

NASA CR-111817  
Part II

# COASTAL-ZONE REQUIREMENTS FOR EOS A/B

Final Report



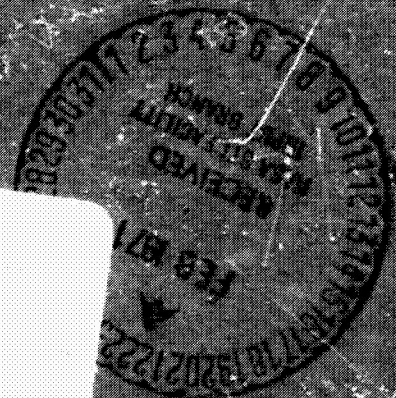
Prepared Under  
CONTRACT NO. NAS1-10280

By  
TRW SYSTEMS GROUP

For  
NATIONAL AERONAUTICS & SPACE ADMINISTRATION

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Hampton, Virginia 23365

N 71-17263



## FINAL REPORT

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# COASTAL-ZONE OCEANOGRAPHIC REQUIREMENTS FOR EARTH OBSERVATORY SATELLITES A & B


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4 February 1971

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## **ABSTRACT**

**This study identified information requirements for effective management and conservation of our Coastal Zones, and determined what significant problem-oriented data could best be provided by space platforms.**

**Information needs were classified into the major priorities of Pollution, Fisheries, Hazards to Shipping and Coastlines, and Geography/Hydrology/ Cartography. Experiment requirements and associated missions were independently developed for each of these, and for a multi-priority mission.**

**Optimum and minimum sensor payload groupings and corresponding requirements were developed for each priority. The merit of performing the selected missions was also established.**

**The results of the study show that there is a significant need for Pollution and Fisheries dedicated payloads. For coastal Geography/Hydrology/ Cartography, there are requirements that EOS A/B\* could fulfill and which will not be provided by other spacecraft in the 1974-76 time frame. A mission dedicated to the Hazards priority would not provide significant additional information beyond that currently planned by other spacecraft programs.**

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**\*Throughout the report EOS A/B is referred to as ERTS E/F.**

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ERTS E/F STUDY  
FINAL REPORT  
APPENDIX A

QUANTITATIVE MEASUREMENT REQUIREMENTS  
FOR THE REMOTE SPACE OBSERVABLES  
AND  
SPACE PROGRAMS CONSIDERED

Explanation of Symbols

- ▲ Solid triangle indicates remote observables that do not relate directly to phenomena of interest or are of secondary importance to the measurement of those phenomena.
- △ Open triangle indicates phenomena that are of secondary importance for the fulfillment of related specific information needs.

Items that are surrounded by a box are measurement requirements that can be satisfied by other space programs than ERTS E/F, which are expected to be operational before or during the ERTS E/F time frame.

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Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Detection and Classification

Applies to  
Fig. 1

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	L.O.V. Miles	Sensitivity $\mu\text{m}^2/\text{ft}^2/\mu$	Observation Frequency Days
<b>POLLUTION INSERTION LOCATIONS AND CAUSE</b>						
<b>1. Point Sources</b>						
Bottom color changes	.4-.7	.01	100	25	.1-1	30
Surface foam	.4-.7	.03	100	10	.01-.1	7
Distribution of isochromes	.4-1.2	.01	100	20	.1-1	7
<b>2. Submerged</b>						
Color indications on surface	.4-.7	.01	100	25	.1-1	1
Atmospheric vapor indications	.4-.7	Bd	$10^4$	100	1-10	7
Surface roughness (glitter)	.4-.7	Bd	100	25	1-10	7
<b>3. Surface</b>						
Color indications on surface	.4-.7	.01	100	25	.1-1	1
Atmospheric vapor indications	.4-.7	Bd	$10^4$	100	1-10	7
Surface roughness (glitter)	.4-.7	Bd	100	25	1-10	7
<b>4. Atmospheric Fallout</b>						
Smog distribution	.4-1.0	.05	$10^4$	100	1-10	7
<b>5. River/Estuarine Insertion</b>						
Turbid water distribution (estuarine circulation)	.4-.7	.01	300	50	.1-1	7
<b>POLLUTION TYPE</b>						
<b>7. Chemical Characteristics</b>						
▲ Persistence (visible characteristics)	.4-.7	.01	100	25	.01-.1	3
<b>10. Physical Characteristics</b>						
Discoloration of receiving waters	.4-.7	.01	100	25	.01-.1	7
<b>12. Natural</b>						
Red tides	.6-1.2	.03	300	50	.1-1	3
Turbidity	.4-.7	.01	300	25	.1-1	7
<b>13. Nonbiological</b>						
Sediment patterns (turbidity)	.4-.7	.01	300	50	.1-1	14

IR Radiometry/Imaging for  
Pollution - Pollution Detection and Classification

Applies to  
Fig. 1

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>POLLUTION INSERTION LOCATIONS AND CAUSE</u>				
1. Point Sources				
Isothermal mapping	100	25	.5	7
2. Submerged				
Emissivity of surface film	100	25	.1	1
3. Surface				
Emissivity of surface film	100	25	.1	1
5. River/Estuarine Insertion				
Thermal plume boundary	300	50	.1	7
Thermal mixing	300	50	.1	7
<u>POLLUTION TYPE</u>				
7. Chemical Characteristics				
▲ Persistence (thermal characteristics)	100	25	.1	3
10. Physical Characteristics				
Film emissivity (apparent temperature)	100	25	.1	3
13. Non-Biological				
Thermal conditions in excess of natural levels	1000	100	.5	7

**Radar Scatterometry/Imaging for  
Pollution – Pollution Detection and Classification**

**Applies to  
Fig. 1**

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>POLLUTION INSERTION LOCATIONS AND CAUSE</u>				
2. Submerged Sea state modifications	10 <sup>3</sup>	25	NBN (0-2)	1
3. Surface Sea state modifications	10 <sup>3</sup>	25	NBN (0-2)	1
<u>POLLUTION TYPE</u>				
10. Physical Characteristics Sea state or surface roughness modification	10 <sup>3</sup>	25	NBN (0-2)	7

Precision Ranging for  
Pollution – Pollution Detection and Classification

Applies to  
Fig. 1

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>POLLUTION INSERTION LOCATIONS AND CAUSE</u> <u>POLLUTION TYPE</u>					

**Microwave Radiometry for  
Pollution – Pollution Detection and Classification**

**Applies to  
Fig. 1**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>POLLUTION INSERTION LOCATIONS AND CAUSE</b>							
1. Point Sources Surface temperature and salinity	25	300	--	--	.5	1	30
2. Submerged Emissivity of surface film	50	10 <sup>3</sup>	--	NBN (0-2)	.1	--	7
3. Surface Emissivity of surface film	50	10 <sup>3</sup>	--	NBN (0-2)	.1	--	7
5. River/Estuarine Insertion Estuarine circulation (surface temperature and salinity)	25	300	--	--	.5	1	3
<b>POLLUTION TYPE</b>							
7. Chemical Characteristics Persistence (emissivity characteristics)	25	500	--	--	.1	--	3
10. Physical Characteristics Film emissivity	25	300	--	NBN (0-2)	.1	--	3
Surface roughness or apparent temperature modification	25	300	--	NBN (0-2)	.1	--	3
13. Non-Biological Thermal addition	25	200	--	--	.5	--	14
River run-off	25	500	--	--	.5	1	14
Desalination plant effluent	25	200	--	--	--	.5	30

Laser Depth Sounding for  
Pollution -Pollution Detection and Classification

Applies to  
Fig. 1

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>POLLUTION INSERTION LOCATIONS AND CAUSE</u>				
<u>POLLUTION TYPE</u>				
13. Non-Biological Sedimentation	500	100	2	90

Visible and Near IR Spectrometry/Imaging for  
Pollution – Pollution Detection and Classification

Applies to  
Fig. 2

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Scan Rate $\mu$	Observation Frequency Days
<b>POLLUTION EXTENT</b>						
1. Pollution Field Boundaries						
Discolored water	.4-.7	.01	100	25	.1-1	7
Surface roughness (glitter analysis)	.4-.7	0.3	300	50	1-10	7
2. Field Patterns						
Discolored water	.4-.7	.01	100	25	.1-1	7
Surface roughness (glitter analysis)	.4-.7	0.3	300	50	1-10	7
3. Field Interfaces						
Discolored water	.4-.7	.01	100	25	.1-1	7
Surface roughness (glitter analysis)	.4-.7	0.3	300	50	1-10	7
<b>POLLUTION INDICATORS</b>						
4. Froth, Foams						
Surface reflectivity contrasts	.4-.7	0.3	300	25	1-10	7
5. Slicks, Debris, Turbidity						
Turbid and discolored water,	.4-.7	.01	300	25	.1-1	1
Surface roughness (glitter)	.4-.7	0.3	300	50	1-10	1
6. Productivity Alteration						
Discolored water	.4-.7	.01	300	25	.1-1	3
Chlorophyll isochromes	.4-1.2	.01	300	25	.1-1	3
Benthic algae	.4-.6	.01	100	25	.1-1	7
9. Luminescence or Fluorescence						
Spectral characteristics of pollutants	.4-.7	.01	100	25	.01-.1	7
10. Indicator Organisms						
Plankton blooms	.4-1.2	.01	100	50	.1-1	3
Extensive surface fish kills	.4-1.2	.01	50	25	.1-1	1

IR Radiometry/Imaging for  
Pollution – Pollution Detection and Classification

Applies to  
Fig. 2

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy %	Observation Frequency Days
<b>POLLUTION EXTENT</b>				
1. Pollution Field Boundaries Thermal conditions in excess of natural levels	100	25	.2	3
2. Field Pattern Thermal conditions in excess of natural levels	100	25	.2	3
3. Field Interfaces Thermal conditions in excess of natural levels	100	25	.2	3
<b>POLLUTION INDICATORS</b>				
4. Froth, Foams Emissivity variations	100	25	.1	7
5. Slicks, Debris, Turbidity Emissivity variations	100	25	.1	7
7. Thermal Abnormalities Thermal conditions in excess of natural levels	300	50	.2	7
8. Saline Abnormalities Temperature correlations	300	50	.1	7

Radar Scatterometry/Imaging for  
Pollution - Pollution Detection and Classification

Applies to  
Fig. 2

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<b>POLLUTION EXTENT</b>				
1. <b>Pollution Field Boundaries</b> Surface film modifications to sea state	100	25	NBN (0-3)	1-7
2. <b>Field Patterns</b> Surface film modifications to sea state	100	25	NBN (0-3)	1-7
3. <b>Field Interfaces</b> Surface film modifications to sea state	100	25	NBN (0-3)	1-7
<b>POLLUTION INDICATORS</b>				
4. <b>Froth, Foams</b> Surface texture	100	25	NBN (0-3)	1
5. <b>Slicks, Debris, Turbidity</b> Surface roughness modifications	100	25	NBN (0-3)	1

Precision Ranging for  
Pollution – Pollution Detection and Classification

Applies to  
Fig. 2

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>POLLUTION EXTENT</u> None					
<u>POLLUTION INDICATORS</u> None					

**Microwave Radiometry for  
Pollution – Pollution Detection and Classification**

**Applies to  
Fig. 2**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>POLLUTION EXTENT</b>							
<b>1. Pollution Field</b>							
Boundaries							
Surface temperature	25	300		-	.2	-	7
Salinity	25	300		-	-	1	7
Roughness (large pollution features)	25	300		NBN (0-3)	-	-	7
<b>POLLUTION INDICATORS</b>							
<b>4. Froth, Foams</b>							
Large-scale emissivity variations	25	300			.1 Equiv.	-	7
<b>5. Slicks, Debris, Turbidity</b>							
Large scale emissivity variations	25	300			.1 Equiv.	-	7
<b>7. Thermal Abnormalities</b>							
Surface temperature and salinity	25	300			.1	1	7
<b>8. Saline Abnormalities</b>							
Surface temperature and salinity	25	300			.1	1	7

Laser Depth Sounding for  
Pollution – Pollution Detection and Classification

Applies to  
Fig. 2

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>POLLUTION EXTENT</u> None				
<u>POLLUTION INDICATORS</u> None				

Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Dynamics

Applies to  
Fig. 3

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/SE/\mu$	Observation Frequency Days
<b>INTENSITY DISTRIBUTION</b>						
1. Surface Patterns						
Reflection color changes (oil slicks, debris, etc.)	.4-1.2	.03	100	25	.1-1	3
Surface roughness	.4-.7	Bd	100	25	1-10	3
2. Surface Indications of Sub- surface Pollutants						
Scattering and reflectivity (e.g., oil slick from sun- ken ship)	.4-1.2	.03	100	25	.1-1	7
Surface roughness	.4-.7	Bd	100	25	1-10	7
3. Decay Gradients from Source						
Variation in spectral qual- ity of water near point source (savage outfall, etc.)	.4-.7	.01	100	10	.01-1	14
4-10. Rates of Advance/Syllical Variations						
Spectral mapping at spec- ified intervals (fossil fuel slicks, outfall form, debris etc.)	.4-.7	.01	100	25	.1-1	1/4-7
11. Shallow Water Accumulation						
Incident reflectivity	.4-1.2	.03	300	50	.1-1	7
(debris, red tides) spectral variations, chlorophyll	.4-1.2	.01	300	50	.1-1	7
Surface roughness	.4-.7	Bd	300	50	1-10	7
12. Shoreline Accumulation						
Shoreline contour, beach pollution (kelp, debris, etc.)	.4-1.2	.03	50	25	.1-1	7
13. Gyres, Eddies, Current Boundary Accumulation						
Water color, tonal contrasts	.4-.7	.01	100	25	.1-1	3
14. Tidal Marsh Accumulation						
Large accumulations of debris, sewage, etc., dis- coloration of vegetation	.4-1.2	.03	100	25	.1-1	7
15. Biological Accumulation						
Major fish kills	.4-1.2	.03	100	25	.1-1	1

**Applies to  
Fig. 3**

1-14

**Radar Scatterometry/Imaging for  
Pollution – Pollution Dynamics**

**Applies to  
Fig. 3**

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<b>INTENSITY DISTRIBUTION</b>				
1. <b>Surface Patterns</b> Surface roughness modifications effected by slicks	500	50	N 3N (0-2)	2
2. <b>Surface Indications of Subsurface Pollutants</b> Wave and slope variations (modification of capillary wave structure)	500	25	NBN (0-2)	7
4 – 5. <b>Rates of Advance/Cyllical Variations</b> Waves and overall surface roughness changes	500	50	NBN (0-2)	4-7
11. <b>Shallow Water Accumulation</b> Overall surface roughness	200	20	NBN (0-2)	7
14. <b>Tidal Marsh Accumulations</b> Areal extent of marshes (land-water boundary)	500	20	NBN (0-2)	30

Precision Ranging for  
Pollution – Pollution Dynamics

Applies to  
Fig. 3

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>INTENSITY DISTRIBUTION</u> None					

**Microwave Radiometry for  
Pollution - Pollution-Dynamics**

**Applies to  
Fig. 3**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>INTENSITY DISTRIBUTION</b>							
1. Surface Patterns Surface roughness, surface temperature and salinity	25	500	-	NBN(0-2)	.1	.5	3
2. Surface Indications of Subsurface Pollu- tants Emissivity proper- ties of surface foam, oil slicks etc.	25	500	-	NBN(0-2)	.1	.1	7
3. Decay Gradients From Surface Saline and thermal variability at source	10	200	-	-	.5	1	14
4 - Rates of Advance/Cyl- 10. lical Variations Isohaline and iso- therm mapping, sur- face roughness	50	500	-	NBN(0-2)	.5	.5	1/4-7
11. Shallow Water Accum- ulation Water surface tem- perature and sali- nity	20	200	-	-	.5	1	3
13. Gyres, Eddies, Cur- rent Boundary Accum- ulation Water mass discrim- ination on the basis of temperature and salinity	50	1000	-	-	.5	.5	7
14. Tidal Marsh Accumula- tion Areal extent of marshes	25	1000	-	-	.5	.5	30

Laser Depth Sounding for  
Pollution - Pollution Dynamics

Applies to  
Fig. 3

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>INTENSITY DISTRIBUTION</u>				
11. Shallow Water Accumulation Sediment accumulation and redistribution	$10^4$	500	.5	90
12. Shoreline Accumulation Changes in nearshore bottom topography	$10^3$	100	.5	90
14. Tidal Marsh Accumulation Sedimentation: Short term (filling in of sludge, etc.) long term (eutrophication)	$10^3$	300	.5	90

Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Dynamics

Applies to  
Fig. 4

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>DISPERSAL MECHANISMS</b>						
1. Source Distribution Distribution of discolored water	.4-.7	.01	300	50	.1-1	1
2. Insertion Rates Water clarity at source	.4-.7	.01	50	10	.1-1	1/4
3. Density/Dilution Vs Depth ▲ Sea floor accumulation at outfall	.4-.7	.01(1)	100	10	.1-1	30
4. Physical State ▲ Indicators of state	.4-1.2	.01	50	10	.1-1	7
6. Emulsification ▲ Foam	.4-1.2	.01	50	25	.01-1	7
9. Precipitation ▲ Bottom color	.4-.6	.01	300	25	.1-1	30
11. Diffusion Rates Turbidity, spectral mapping of pollutant drift	.4-.7	.01	300	50	.01-.1	1
12. Current Circulation Turbidity, spectral mapping of pollutant drift current boundaries	.4-.7	.01	300	50	.01-.1	1
13 - Tidal Flushing/River Plumes 14. Turbidity, spectral mapping of pollutant drift	.4-.7	.01	300	50	.01-.1	1/4
16. Wind Drift ▲ Sea state (glitter analysis)	.4-.7	.3	300	Glitter Pattern	1-10	1
Drift of surface pollutants	.4-.7	.01	300	50	.1-1	1
17. Surface and Mixed Layer Turbulence ▲ Turbidity	.4-.7	.01	300	50	.1-1	3
Sea state (glitter analysis)	.4-.7	.3	300	Glitter Pattern	1-10	3

IR Radiometry/Imaging for  
Pollution - Pollution Dynamics

Applies to  
Fig. 4

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>DISPERSAL MECHANISMS</u>				
1. Source Distribution Thermal pollution	100	25	.2	7
2 - Insertion Rates, Density/Physical State				
4. Thermal maps	300	50	.2	7
6. Emulsification				
▲ Foam	50	25	.1	7
10. Evaporation				
▲ Emissivity indications and evaporation rates	300	25	.1	7
15. Buoyant Forces				
Surface temperature	300	25	.2	7

Radar Scatterometry/Imaging for  
Pollution - Pollution Dynamics

Applies to  
Fig. 4

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>DISPERSAL MECHANISMS</u>				
6. Emulsification ▲ Foam	50	25	NBN(0-2)	7
16 - Wind Drift, Surface and Mixed Layer Turbulence 17. Sea state ▲	1000	100	NBN(0-4)	1

Precision Ranging for  
Pollution - Pollution Dynamics

Applies to  
Fig. 4

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>DISPERSAL MECHANISMS</u> None					

Microwave Radiometry for  
Pollution - Pollution Dynamics

Applies to  
Fig. 4

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>DISPERSAL MECHANISMS</b>							
1 - Insertion Characteristics							
4. Mapping to determine pattern of dispersion from source	25	50	-	-	.2	1	1/4-3
6. Emulsification							
▲ Foam	25	50	-	NBN (0-4)	.1	1	7
10. Evaporation							
▲ Change in salinity concentrations in regions of intense evaporation	25	300	-	-	-	1	7
12. Current Circulation							
Current pattern recognition on basis of temperature and salinity contrasts	50	300	-	-	.1	1/2	11
13. Tidal Flushing							
Tidal mixing in estuaries by observing salinity concentrations	50	300	-	-	-	1	1/4
14. River Plumes							
Extension of rivers into the sea	50	500	-	-	.2	2	1/4-3
15. Buoyant Forces							
Surface salinity and temperature	25	100	-	-	.2	1	1
16 - Wind Drift/Mixed Layer							
17. Turbulence							
▲ Sea state	100	1000	-	NBN (0-4)	-	-	1

Laser Depth Sounding for  
Pollution - Pollution Dynamics

Applies to  
Fig. 4

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>DISPERSAL MECHANISMS</u>				
1. Source Distribution Bottom topography	1000	200	3	90
2. Insertion Rates ▲ Sedimentation rates bottom topography	1000	200	3	90
11. Diffusion Rates Sediment accumulation	1000	200	3	90
14. River Plumes Sedimentation	1000	200	3	90

Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Dynamics

Applies to  
Fig. 5

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<u>ENVIRONMENTAL ACCOMMODATION</u>						
1. Reaction Rates						
▲ Indications of Chemical Composition Changes	.4-.7	.01	300	25	.01-.1	14
2. Toxicants						
Surface Fish Kills	.4-1.2	.03	100	10	.1-1	1
3. Precipitants						
Distribution of Turbid Water (Especially in Estuaries)	.4-.7	.01	300	25	.1-1	7
4. End Products						
▲ Spectral Survey to Determine Water Composition	.4-.7	.01	300	10	.01-.1	7
5.- Biological Stimulants						
9. Chlorophyll (As Index of Productivity)	.4-1.2	.01	300	25	.1-1	3
13. Dilution						
Distribution of Discolored Water Relative to Source	.4-.7	.01	100	25	.1-1	7

IR Radiometry/Imaging for  
Pollution - Pollution Dynamics

Applies to  
Fig. 5

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>ENVIRONMENTAL ACCOMMODATION</u>				
2. Toxicants ▲ Temperature Indications of Toxicant Concentra- tions	100	25	0.1	7
4. End Products ▲ Emissivity Characteristics of Pollutant End Products	300	20	0.1	7
11. Bacterial Breakdown ▲ Emissivity Changes Due Localized Biodegradation	1000	25	0.1	7
13. Dilution Pattern of Dispersal of Thermal Discharge From Power Stations	1000	25	0.1	30

Radar Scatterometry/Imaging for  
Pollution - Pollution Dynamics

Applies to  
Fig. 5

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>ENVIRONMENTAL ACCOMMODATION</u> None				

Precision Ranging for  
Pollution - Pollution Dynamics

Applies to  
Fig. 5

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>ENVIRONMENTAL ACCOMMODATION</u> None					

**Microwave Radiometry for  
Pollution - Pollution Dynamics**

**Applies to  
Fig. 5**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>ENVIRONMENTAL ACCOMMODATION</u>							
1.- Reaction Rates/Toxi- 3. cants/Precipitants ▲ Emissivity Varia- tions Due to Changes in the Chemical Properties of the Water Column	25	300	-	-	0.1	0.5	7
4. End Products ▲ Emissivity Charac- teristics of Pollu- tant End Products	25	200	-	-	0.1	0.5	7
11. Bacterial Breakdown ▲ Emissivity Changes Due to Localized Biodegradation	25	500	-	-	0.1	0.5	7
13. Dilution Pattern of Dispersal of Thermal Discharge From Power Stations	20	1000	-	-	0.1	-	30

Laser Depth Sounding for  
Pollution - Pollution Dynamics

Applies to  
Fig. 5

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>ENVIRONMENTAL ACCOMMODATION</u> 3.- Precipitants/End Products 4. Sedimentation	$10^3$	200	0.5	90

Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 6

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>IMPINGEMENT ON ESTHETIC VALUES</b>						
1. Decaying Debris Large accumulations (kelp, etc.)	.4-1.2	.03	100	25	.1-1	7
2. Water Contamination ▲ Absorption spectrometry for volatile impurities	.4-.7	.01	300	50	.01-1	3
3. Biological Kills Color correlations (red tides, oil slicks, water pollution, dead fish)	.4-1.2	.01	100	50	.1-1	1
4. Coastal Industries Air circulation patterns Water pollution detection	.4-.7	.01	10000 100	100 50	.1-1 .1-1	3
5. Dead or Dying Wildlife Direct detection of dead wildlife	.4-1.2	.03	50	10	.1-1	7
6. Beach Debris Large accumulations (kelp, etc.)	.4-1.2	.03	100	25	.1-1	7
7. Altered Coastal Vegetation Spectral imagery (browning of coastal vegetation)	.4-1.2	.03	100	50	.1-1	14
8. Water Discoloration (Slick and Debris) Spectral imagery (fossil fuels, etc.) Surface roughness	.4-.7 .4-.7	.01 Bd	50 50	25 25	.1-1 1-10	1 1
9. Coastal Construction Coastline alternations Sedimentation Turbidity ▲ Wave refraction	.4-.7 .4-.7 .4-.7 .4-.7	.1 .01 .01 0.3	50 100 100 100	50 50 50 25	.1-1 .1-1 .1-1 .1-1	30 30 7 7
10. Slimy Water Spectral identification Surface roughness	.4-.7 .4-.7	.01 Bd	100 100	25 25	.1-1 1-10	7 7
11. Sludgy Bottoms Shallow water color	.4-.7	.01(1)	100	25	.1-1	14

**Applies to  
Fig. 6**

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<u>IMPINGEMENT ON ESTHETIC VALUES</u>						
12. Beach and Bottom Debris						
Shallow Water Buildup	.4-.7	.01(1)	100	25	.1-1	30
Large Scale Beach Debris	.4-.7	.03	50	25	.1-1	14
13. Sticky Tars						
Large Scale Floating and Beach Deposits	.4-.7	.03	50	25	.1-1	7

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IR Radiometry/Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 6

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>IMPINGEMENT ON ESTHETIC VALUES</u>				
3. Biological Kills				
▲ Thermal Pollution	500	25	1	30
5. Dead or Dying Wildlife Potential for Thermal Kills (Critical Levels)	500	25	1	30
7. Altered Coastal Vegetation				
▲ Thermal Correlations	300	25	0.5	30
8. Water Discoloration (Slicks and Debris) Detection of Slicks Through Emissivity Variations	500	25	0.1	30
10. Slimy Water				
▲ Thermal Correlations with Slime Production	1000	25	1	30
13. Sticky Tars				
Thermal Detection	50	25	1	30

# Radar Scatterometry/ Imaging for

Applies to  
Fig.6

Pollution - Pollution Effects

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>IMPINGEMENT ON ESTHETIC VALUES</u>				
8. Water Discoloration (Slick and Debris) ▲ Slick effects on sea state (capillary structure)	300	20	NBN(0-2)	30
9. Coastal Construction ▲ Surf modifications	100	10	NBN(2-4)	60
10. Slimy Water ▲ Wave damping effects	1000	20	NBN(0-2)	30
				1-33

Precision Ranging for  
Pollution - Pollution Effects

Applies to  
Fig. 6

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>IMPINGEMENT ON ESTHETIC VALUES</u> None					

Microwave Radiometry for  
Pollution - Pollution Dynamics

Applies to  
Fig. 6

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>IMPINGEMENT ON ESTHETIC VALUES</u>							
3. Biological Kills ▲ Salinity Temperature	25	10 <sup>4</sup>	-	-	1	1	30
5. Dead or Dying Wildlife Potential for Thermal and Salinity Kills (Critical Levels)	25	10 <sup>4</sup>	-	-	1	1	30
7. Altered Coastal Vegetation ▲ Thermal and Salinity Correlations	25	10 <sup>3</sup>	-	-	1	1	30
10. Slimy Water ▲ Thermal Correlations	25	10 <sup>3</sup>	-	-	1	-	30
13. Sticky Tars Thermal Detection	10	50	-	-	1	-	30

Laser Depth Sounding for  
Pollution - Pollution Dynamics

Applies to  
Fig. 6

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>IMPINGEMENT ON ESTHETIC VALUES</u>				
9. Coastal Construction Water Depth Variations in Coastal Waters	10 <sup>3</sup>	100	1	60
11. Sludgy Bottoms Sludge Buildup	10 <sup>3</sup>	100	0.5	60
12. Beach and Bottom Debris ▲ Coastal Water Depth Changes Due to Debris Accumulation	10 <sup>3</sup>	100	1	60

Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 7

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>EFFECTS ON THE MARINE ECOSYSTEM</b>						
1. Nutrient Insertion Zones of productivity (chlorophyll), turbidity	.4-1.2	.01	300	50	.1-1	3
3. Altered Light Penetration Shallow water bottom color changes	.4-.7	.01(1)	100	25	.1-1	14
Turbidity	.4-.7	.01	300	50	.1-1	7
▲ Surface aquaculture	.4-1.2	.03	300	25	.1-1	14
4. Thermal Stimulation Productivity (chlorophyll)	.4-1.2	.01	300	50	.1-1	3
5. Water Mass Mixing Color patterns indicative of mixing	.4-.7	.01	300	25	.1-1	7
6. Organic Deposition and Shoaling ▲ Bottom color variation in shallow waters	.4-.7	.01(1)	100	25	.1-1	30
7. Altered Fecundity or Growth Rates Size and abundance of fish schools	.4-1.2	.01	50	50	.1-1	7
8. Catastrophic Mortalities Altered benthic and pelagic productivity	.4-.6	.01	50	25	.1-1	3
9. Encouragement of Undesirable Species Extensive single-species Population explosion (e.g., red tides)	.4-1.2	.03	300	50	.1-1	3
	.4-1.2	.03	300	50	.1-1	3
10. Biomass Production Indications of productivity	.4-.7	.01	300	50	.1-1	3
11. Reduced Diversity ▲ Size and frequency of fish schools	.4-1.2	.01	50	50	.1-1	7
13. Environmental Alteration Light penetration Nutrients Productivity (chlorophyll)	.4-1.2	.01	300	50	.1-1	7
Turbidity	.4-.7	.01	300	50	.1-1	7
Sedimentation	.4-.7	.03	300	50	.1-1	7
						1-37

Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 7

Applications	Wavelength $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<u>EFFECTS ON THE MARINE ECOSYSTEM</u>						
14. Photosynthetic Inhibition						
▲ Turbidity						
Productivity (chlorophyll)	.4-.7	.01	300	50	.1-1	7
Concentration	.4-1.2	.01	300	50	.1-1	7
15. Pathological Effects						
▲ Visible benthic and pelagic alterations	.4-.7	.01	100	25	.1-1	14
Pollution levels	.4-.7	.01	300	25	.1-1	14

IR Radiometry/Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 7

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>EFFECTS ON THE MARINE ECOSYSTEM</u>				
1. Nutrient Insertion Point source or outfall location through isothermal mapping	100	25	.1	3
4. Thermal Stimulation Distribution of isotherms	100	25	.2	3
5. Water Mass Mixing Thermal patterns indicative of mixing	300	50	.1	3
13. Environmental Alteration Temperature alterations	500	50	.2	7

Radar Scatterometry/ Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 7

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>EFFECTS ON THE MARINE ECOSYSTEM</u> 8. Catastrophic Mortalities ▲ Surface films	50	25	NBN (0-4)	1

Precision Ranging for  
Pollution - Pollution Effects

Applies to  
Fig. 7

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>EFFECTS ON THE MARINE ECOSYSTEM</u> None					

**Microwave Radiometry for  
Pollution - Pollution Effects**

**Applies to  
Fig. 7**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>EFFECTS ON THE MARINE ECOSYSTEM</u>							
1. Nutrient Insertion (Salinity, tempera- ture) outfalls, river runoff	50	500	-	-	.2	2	3
4. Thermal Stimulation Distribution of isotherms	25	100	-	-	.2	-	3
5. Water Mass Mixing Thermal and salinity patterns	50	300			.1	1	3
9. Encouragement of Unde- sirable Species ▲ Salinity thermal inducement	50	300			.2	1	3
13. Environmental Altera- tion Salinity temperature alterations	50	500			.2	1	7

**Applies to  
Fig. 7**

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>EFFECTS ON THE MARINE ECOSYSTEM</u>				
6. Organic Deposition and Shoaling Bottom buildup	1000	200	3	90
13. Environmental Alteration Depth alterations due to sedimentation, erosion, waste	1000	200	3	90

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Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 8

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>EFFECTS ON HUMAN HEALTH AND SAFETY</b>						
3. Reduced Protein Availability						
▲ Benthic die-offs which cause color changes	.4-1.2	.03	50	25	.1-1	7
Surface evidence of fish	.4-.7	Bd	50	25	1-10	7
8. Recreational Hazards						
▲ Beach survey of large accumulation of debris	.4-.7	.01(2)	100	25	.1-1	7
Evidence of bottom debris (bottom color, wave refractive patterns)	.4-.7	.01	100	25	.1-1	7
9. Toxic Swimming Waters						
10. Infectious Waters						
Spectral line detection of individual pollutants (e.g., tracing of sewage dispersion patterns)	.4-.7	.01	100	25	.01-1	7

IR Radiometry/Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 8

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>EFFECTS ON HUMAN HEALTH AND SAFETY</u> 9. Toxic Swimming Waters Isothermal mapping for pollutant circulation patterns 10. Infectious Waters	300	25	.1	1

Radar Scatterometry/Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 8

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>EFFECTS ON HUMAN HEALTH AND SAFETY</u> 8. Recreational Hazards ▲ Surface Wave and Roughness Indications or Accumulations of Bottom Debris	100	25	1	7

Precision Ranging for  
Pollution - Pollution Effects

Applies to  
Fig. 8

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>EFFECTS ON HUMAN HEALTH AND SAFETY</u> None					

**Microwave Radiometry for  
Pollution-Pollution Effects**

**Applies to  
Fig. 8**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>EFFECTS ON HUMAN HEALTH AND SAFETY</b> 9. Toxic swimming waters 10. Infectious waters  Isotherm and isohaline mapping of pollution insertion and distribution	25	300	-	-	.1	1	1

Laser Depth Sounding for  
Pollution - Pollution Effects

Applies to  
Fig. 8

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>EFFECTS ON HUMAN HEALTH AND SAFETY</u> 8. Recreational Hazards ▲ Bottom Profiles	50	50	3	30 or INT

Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 9

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>EFFECTS ON COASTAL OPERATIONS</b>						
1. Siltation and Dumping Color indications of bottom changes (e.g., bottom con- tour changes in shipping channels)	.4-.7	.01(1)	300	25	.1-1	14
▲ 2. Combustible Slicks ▲ Surface roughness (glitter), spectral properties of reflected light	.4-.7	.3	300	50	.1-10	7
▲ 3. Floating Debris ▲ Visible survey for large accumulations of surface debris	.4-.7	.03	200	25	.1-1	4
4. Gear Damage ▲ Bottom debris	.4-.7	.01(1)	100	25	.1-1	14
5. Depleted or Inedible Stocks Visible indications of ur- face fish kills	.4-1.2	.03	50	10	.1-1	7
▲ Oil slicks near shore (color)	.4-1.2	.03	300	10	.1-1	7
(glitter)	.4-.7	3d	300	10	1-10	7
Red tides	.6-1.2	.03	1000	25	.1-1	14
9. Toxicants ▲ Spectral line of detection o of specific pollutants	.4-.7	.01	1000	25	.01-.1	30
Oil slicks (color)	.4-1.2	.03	300	10	.1-1	30
(glitter)	.4-.7	3d	300	10	1-10	30
10. Turbidity Water clarity and color	.4-.7	.03	1000	25	.1-1	30
11. Salinity and Temperature Levels Changes in distribution and quantity of algae, especially kelp	.4-1.2	.03	50	25	.1-1	30
12. Nutrient Availability Chlorophyll content	.4-1.2	.01	300	25	.1-1	14
14. Surface Sports Floating debris	.4-1.2	.03	50	25	.1-1	7
Oil slicks (color)	.4-1.2	.03	1000	25	.1-1	7
(glitter)	.4-.7	Bd	1000	25	1-10	7
Red tides	.4-1.2	.03	7000	25	.1-1	14
15. Sport Fishing						1-49

**Applies to  
Fig. 9**

1-50

IR Radiometry/Imaging for  
Pollution - Pollution Effects

Applies to  
Fig. 9

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>EFFECTS ON COASTAL OPERATIONS</u>				
▲ 3. Floating Debris ▲ Large accumulations of surface debris	500	25	.1	7
5. Depleted or Inedible Stocks ▲ Oil slicks near shore	500	10	.1	14
9. Toxicants Isothermal mapping for pollutant circulation patterns	1000	25	.1	30
11. Salinity and Temperature Levels Thermal mapping	2000	25	.2	30
12. Nutrient Availability Tracing of current patterns by thermal mapping to determine distribution of sewage and river run-off	1000	50	.2	3
14. Surface Sports Oil slicks near shore	1000	25	.1	7
15. Sport Fishing				
16. Underwater Sports Tracing of current patterns by thermal mapping to determine distribution of fish and pollutants	500	50	.1	7

**Radar Scatterometry/Imaging**  
**Pollution - Pollution Effects**

**Applies to  
Fig. 9**

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>EFFECTS ON COASTAL OPERATIONS</u>				
1. Siltation and Dumping Wave refractive patterns indicative of shoal water	300	50	NBN(0-4)	90
△ 2. Combustible Slicks ▲ Surface roughness	300	50	NBN(0-6)	3
△ 3. Floating Debris ▲ Large accumulations of surface debris	300	50		3
5. Depleted or Inedible Stocks ▲ Surface roughness modification due to oil slicks	1000	50	NBN(0-6)	7
9. Toxicants ▲ Changes in overall roughness (e.g., oil slicks)	300	50	NBN(0-6)	3
14. Surface Sports Surface roughness modification by oil slicks	1000	25	NBN(0-4)	4

Precision Ranging for  
Pollution - Pollution Effects

Applies to  
Fig. 9

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>EFFECTS ON COASTAL OPERATIONS</u> None					



Microwave Radiometry for  
Pollution - Pollution Effects (Cont'd)

Applies to  
Fig. 9

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>EFFECTS ON COASTAL OPERATIONS</u> 16. Underwater Sports Tracing of current patterns by thermal or salinity mapping to determine distribution of fish and pollutants	50	2000	-	-	0.5	1	30

# Laser Depth Sounding for

Pollution - Pollution Effects

Applies to  
Fig. 9

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>EFFECTS ON COASTAL OPERATIONS</u>				
1. Siltation and Dumping Development of shoal water	300	50	3	90
4. Gear Damage ▲ Bottom irregularities indicative of submerged objects	100	25	5	30

Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Control

Applies to  
Fig. 10

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<u>OPTIMAL SURFACE CLEAN-UP TECHNIQUES</u>						
1. Distribution Mapping						
Spectral mapping of pollutant extent	.4-.7	.01	100	50	.1-1	1
Surface roughness (glitter)	.4-.7	Bd	100	50	1-10	1
2. Chemical or Spectral Tagging						
Spectral line detection of pollutant types and extent	.4-.7	.01	100	25	.1-1	1
3. Clean-up Management						
Spectral line detection of pollutant types and extent	.4-.7	.01	100	25	.1-1	1
Interpretation of clean-up success	.6-1.2	.01	100	25	.01-.1	1
4. Barriers						
Spectral analysis of success	.6-1.2	.03	100	25	.01-.1	1
5. Chemicals						
Spectral analysis of success	.6-1.2	.03	100	25	.01-.1	1

IR Radiometry/Imaging for  
Pollution - Pollution Control

Applies to  
Fig. 10

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>OPTIMAL SURFACE CLEAN-UP TECHNIQUES</u>				
1. Distribution Mapping Isotherm mapping	300	50	.1	1
2. Chemical or Spectral Tagging Isotherm mapping	300	50	.1	1
3. Clean-up Management Isotherm mapping	300	50	.1	1
4. Barriers ▲ Isotherm mapping to determine containment success	300	25	.1	1
5. Chemicals ▲ Isotherm mapping to determine containment success	300	25	.1	1

Radar Spectrometry/Imaging for  
Pollution - Pollution Control

Applies to  
Fig. 10

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>OPTIMAL SURFACE CLEAN-UP TECHNIQUES</u>				
1. Distribution Mapping Waves and overall surface roughness (indicative of surface slicks and bottom discontinuities)	300	50	NBN(0-6)	1
4. Barriers Effect of waves and surface roughness on barrier containment	300	25	NBN(0-5)	1

Precision Ranging for  
Pollution - Pollution Control

Applies to  
Fig. 10

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>OPTIMAL SURFACE CLEAN-UP TECHNIQUES</u> None					

Microwave Radiometry for  
Pollution - Pollution Control

Applies to  
Fig. 10

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>OPTIMAL SURFACE CLEAN-UP TECHNIQUES</u>							
1. Distribution Mapping Surface roughness isotherm and isoha- line mapping	50	300	-	NBN(0-6)	.1	1	1
2. Chemical or Spectral Tagging (Same as above)							
3. Clean-up Management (Same as above)							
4. Barriers Surface roughness salinity and temper- ature mapping to determine contain- ment success	25	300	-	NBN(0-5)	.1	1	1
5. Chemicals (Same as above)							

Laser Depth Sounding for  
Pollution - Pollution Control

Applies to  
Fig. 10

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>OPTIMAL SURFACE CLEAN-UP TECHNIQUES</u> 1. Distribution Mapping ▲ Bottom topography sedimentation  3. Clean-up Management ▲ Bottom topography sedimentation				

Visible and Near IR Spectrometry-Imaging for  
Pollution - Pollution Control

Applies to  
Fig. 11

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<u>IMPROVED DISPERSION</u>						
1. Diffusers Spectral analysis of pollutant distribution (comparison before and after)	.4-.7	.01	100	25	.1-1	1 (INT)
2. Buoyancy Control (Same as above)						
3. Increased Flow (Same as above)						
4. Channels (Same as above)						
5. Weirs, Grains, Etc. (Same as above)						
6. Circulation						
Current boundaries	.4-.7	.01	300	100	.1-1	7
Convergence	.4-.7	.01	1000	200	.1-1	7
Divergence	.4-.7	.01	1000	200	.1-1	7
7. Bottom Topography Color indications of bottom discontinuities	.4-.7	.01(1)	100	25	.1-1	INT

IR Radiometry/Imaging for  
Pollution - Pollution Control

Applies to  
Fig. 11

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>IMPROVED DISPERSION</u>				
1. Diffusers Isotherm mapping	100	25	.2	7
2. Buoyancy Control Isotherm mapping	100	25	.2	7
3. Increased Flow Isotherm mapping	100	25	.2	7
4. Channels Isotherm mapping	100	25	.2	7
5. Weirs, Grains, Etc. Isotherm mapping	100	25	.2	7
6. Circulation Current boundaries	300	50	.1	1/4-14
9. Water Density Profile ▲ Indirect layer depth determination				

Radar Scatterometry/Imaging for  
Pollution - Pollution Control

Applies to  
Fig. 11

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<p><u>IMPROVED DISPERSION</u></p> <p>7. Bottom Topography</p> <p>▲ Overall roughness indications of bottom formations</p>	500	50	NBN(0-3)	INT

Precision Ranging for  
Pollution - Pollution Control

Applies to  
Fig. 11

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>IMPROVED DISPERSION</u>					

**Microwave Radiometry for  
Pollution - Pollution Control**

**Applies to  
Fig. 11**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>IMPROVED DISPERSION</u>							
1. Diffusers Isotherm and isohaline mapping	25	100	-	-	.2	1	7
2. Buoyancy Control Isotherm and isohaline mapping	25	100	-	-	.2	1	7
3. Increased Flow Isotherm and isohaline mapping	25	100	-	-	.2	1	7
4. Channels Isotherm and isohaline mapping	25	100	-	-	.2	1	7
5. Weirs, Grains, Etc. Isotherm and isohaline mapping	25	100	-	-	.2	1	7

Laser Depth Sounding for  
Pollution - Pollution Control

Applies to  
Fig. 11

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>IMPROVED DISPERSION</u>				
6. Circulation Bottom contour	500	100	5	180
7. Bottom Topography Bottom contour	500	100	5	180
8. Tidal Flushing Bottom contour	500	100	5	180

Visible and Near IR Spectrometry/Imaging for  
Pollution - Pollution Control

Applies to  
Fig. 12

Applications	Spectral Range	Spectral Bandwidth	Ground Resolution Feet	F.O.V. Miles	Sensitivity w/m <sup>2</sup> /ST/	Observation Frequency Days
<u>IMPROVED TREATMENT</u>						
1. Bacterial Processing						
Effect upon organisms	.4-1.2	.01	100	25	.1-1	7
Spectral Analysis of pollutant extent	.4-.7	.01	100	25	.01-.1	7
2. Detoxification (Same as above)						
3. Physical State Change (Same as above)						
4. Sterilization (Same as above)						
5. Dilution (Same as above)						
6. Filtering (Same as above)						
7. Coagulation (Same as above)						
8. Adsorption (Same as above)						
<u>OTHER CONTROL MECHANISMS</u>						
9. Adapt Insertion to Tidal and Other Cycles						
Map surface patterns	.4-.7	.01	100	25	.1-1	1/4-3
10. Recycle Critical Pollutents						
Map surface patterns	.4-.7	.01	100	25	.1-1	3
11. Critical Level Plant Shutdowns						
Spectral survey of critical atmospheric and water pollu- tion levels						
▲ Smoke trails						
12. Use of Biodegradable Chemicals and Materials						
▲ Color changes in receiving waters attending introduction of biodegradables	.4-.7	.01	100	25	.1-1	1 INT

IR Radiometry/Imaging for  
Pollution - Pollution Control

Applies to  
Fig. 12

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>IMPROVED TREATMENT</u>				
▲ 1. Bacterial Processing Isothermal mapping	25	100	.1	14+INT
▲ 2. Detoxification Isothermal mapping	25	100	.1	14+INT
▲ 3. Physical State Change Isothermal mapping	25	100	.1	14+INT
▲ 4. Sterilization Isothermal mapping	25	100	.1	14+INT
▲ 5. Dilution Isothermal mapping	25	100	.1	14+INT
▲ 6. Filtering Isothermal mapping	25	100	.1	14+INT
▲ 7. Coagulation Isothermal mapping	25	100	.1	14+INT
▲ 8. Adsorption Isothermal mapping	25	100	.1	14+INT
<u>OTHER CONTROL MECHANISMS</u>				
11. Critical Level Plant Shutdowns Thermal conditions indicative of critical pollution levels at source or outfall	25	300	.2	1

Radar Scatterometry/Imaging for  
Pollution - Pollution Control

Applies to  
Fig. 12

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>IMPROVED TREATMENT</u> None				
<u>OTHER CONTROL MECHANISMS</u> None				

Precision Ranging for  
Pollution - Pollution Control

Applies to  
Fig. 12

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter: Feet	Accuracy cm	Observation Frequency Days
<u>IMPROVED TREATMENT</u> None					
<u>OTHER CONTROL MECHANISMS</u> None					

Microwave Radiometry for  
Pollution - Pollution Control

Applies to  
Fig. 12

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>IMPROVED TREATMENT</u>							
▲ 1. Bacterial Processing Variations in salinity concentrations	25	100	-	-	-	1	14 INT
▲ 2. Detoxification (Same as above)							
▲ 3. Physical State Change (Same as above)							
▲ 4. Sterilization (Same as above)							
▲ 5. Dilution (Same as above)							
▲ 6. Filtering (Same as above)							
▲ 7. Coagulation (Same as above)							
▲ 8. Adsorption (Same as above)							
<u>OTHER CONTROL MECHANISMS</u>							
12. Use of Biodegradable Chemicals and Materials	25	100	-	-	.1 (Equiv)	-	INT
▲ Emissivity as an index of effectiveness of use of biodegradables							

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Laser Depth Sounding for  
Pollution - Pollution Control

Applies to  
Fig. 12

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>IMPROVED TREATMENT</u> None				
<u>OTHER CONTROL MECHANISMS</u> None				

Visible and Near IR Spectrometry/Imaging for  
Fisheries - Stock Management - Tropho Dynamic Information,  
and Life History Information

Applies to  
Fig. 13

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<u>TROPHO-DYNAMIC INFORMATION</u>						
<u>LIFE HISTORY INFORMATION</u>						
4. Schooling Characteristics						
School size and shape	.4-.7	.05	10	50	.1-1.0	INT
▲ Natural slicks (glitter pattern)	.4-.7	Bd	100	50	1-10	INT
Sea state	.4-.7	Bd	1000	100	1-10	INT
Association with visible features	.4-.7	Bd	50	50	.1-1.0	INT
5. Migratory Behavior						
Location of near-surface schools	.4-.7	.05	50	50	.1-1.0	5
Water color	.4-1.2	.05	1000	200	.1-1.0	5

# IR Radiometry/Imaging for

Fisheries - Stock Management - Tropho Dynamic Information,  
and Life History Information

Applies to  
Fig. 13

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>TROPHO-DYNAMIC INFORMATION</u>				
<u>LIFE HISTORY INFORMATION</u>				
4. Schooling Characteristics				
School size and shape	10	50		INT
▲ Natural slicks	100	50		INT
Association with thermal features	50	50	1.0	INT
5. Migratory Behavior				
Location of near-surface schools	50	50		5
Disposition of surface isotherms	1000	200	0.5	5

Radar Scatterometry/Imaging for  
 Fisheries - Stock Management - Tropho Dynamic Information,  
 and Life History Information

Applies to  
 Fig. 13

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>TROPHO-DYNAMIC INFORMATION</u>				
<u>LIFE HISTORY INFORMATION</u>				
4. Schooling Characteristics				
▲ Surface roughness due to breezing schools	50	50	NBN(0-12)	INT
Sea state	NA	50		INT
5. Migratory Behavior				
Surface roughness due to breezing schools	50	50		5

Precision Ranging for

Applies to  
Fig. 13

Fisheries - Stock Management - Tropho Dynamic Information,  
and Life History Information

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>TROPHO-DYNAMIC INFORMATION</u>					
<u>LIFE HISTORY INFORMATION</u>					

**Microwave Radiometry for**  
**Fisheries - Stock Management - Tropho Dynamic Information,**  
**and Life History Information**

**Applies to**  
**Fig. 13**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>TROPHO-DYNAMIC INFORMATION</u>							
<u>LIFE HISTORY INFORMATION</u>							
4. Schooling Characteristics Surface roughness	50	NA		NBN (0-12)			INT
5. Migratory Behavior Disposition of isotherms and isohalines	200	1000			0.5	0.5	5
						2-5	

Laser Depth Sounding for  
Fisheries - Stock Management - Tropho Dynamic Information,  
and Life History Information

Applies to  
Fig. 13

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>TROPHO-DYNAMIC INFORMATION</u>				
<u>LIFE HISTORY INFORMATION</u>				
4. Schooling Characteristics Depth of school	100	20	5	INT
5. Migratory Behavior Depth of school	100	20	5	INT

Visible and Near IR Spectrometry/Imaging for  
 Fisheries - Stock Management - Year Class Spawning Success,  
 Egg and Larval Survivability, and Effect of Fishing

Applies to  
 Fig. 14

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<u>YEAR CLASS SPAWNING SUCCESS</u>						
1. Environmental Conditions in Spawning Areas						
Chlorophyll	.4-1.2	.05	1000	50	.1-1.0	7
Sea state	.4-.7	Bd	1000	100	1-10	7
▲ Presence of oil slicks (glitter pattern)	.4-.7	Bd	100	50	1-10	7
Chemical pollution (water color)	.4-1.2	.05	100	50	.01-.1	7
Turbidity	.4-.7	.1	100	50	.1-1.0	7
Water depth	.4-.7	.02	100	50	.1-1.0	30
2. Availability and Condition of Breeding Stock						
Presence of near-surface schools	.4-.7	.05	50	50	.1-1.0	7
<u>EGG AND LARVAL SURVIVABILITY</u>						
3. Intensity of Predation and/or Competition						
Abundance of surface schools	.4-.7	.05	50	50	.1-1.0	7
▲ Presence of slicks due to feeding	.4-.7	Bd	100	50	1-10	7
4. Availability of Suitable Bottom Conditions						
Kelp presence	.6-1.2	.02	50	50	.1-1	30
Pollution spectra	.4-1.2	.05	100	50	.01-.1	7
Turbidity	.4-.7	.05	100	50	.1-1.0	3
Shallow water spectral shift (for bottom depth and composition)	.4-.7	.01	100	50	.1-1.0	30
5. Departure from Suitable Water Mass Conditions						
Chlorophyll	.4-1.2	.05	1000	50	.1-1.0	3
Chemical pollution (water color)	.4-1.2	.05	100	50	.01-.1	3
6. Availability of Forage						
Chlorophyll	.4-1.2	.05	1000	50	.1-1.0	3
<u>EFFECT OF FISHING</u>						
7. Catch Fleet Efficiency						
Monitoring of boat-days in the fishing grounds	.4-.7	Bd	25	100	1-10	1
						2-7

IR Radiometry/Imaging for  
 Fisheries - Stock Management-Year Class Spawning Success,  
 Egg and Larval Survivability, and Effect of Fishing

Applies to  
 Fig. 14

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>YEAR CLASS SPAWNING SUCCESS</u>				
1. Environmental Conditions in Spawning Areas Disposition of surface isotherms	1000	50		7
2. Availability and Condition of Breeding Stock Presence of surface schools	50	50		7
<u>EGG AND LARVAL SURVIVABILITY</u>				
3. Intensity of Predation and/or Competition Abundance of surface schools (thermal pattern)	50	50		7
▲ Presence of slicks due to feeding	100	50		7
5. Departure from Suitable Water Mass Conditions Disposition of surface isotherms	1000	50		7
<u>EFFECT OF FISHING</u>				
7. Catch Fleet Efficiency Monitoring of boat-days in the fishing grounds	25	100		1

Radar Scatterometry/Imaging for

Applies to  
Fig. 14

Fisheries - Stock Management - Year Class Spawning Success,  
Egg and Larval Survivability, and Effect of Fishing

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>YEAR CLASS SPAWNING SUCCESS</u>				
1. Environmental Conditions in Spawning Areas				
▲ Presence of petroleum slicks	100	50	NBN(0-12)	7
Surface roughness	NA	50		7
<u>EGG AND LARVAL SURVIVABILITY</u>				
3. Intensity of Predation and/or Competition				
Abundance of surface schools (roughness)	50	50		7
▲ Presence of slicks due to feeding	100	50		7
<u>EFFECT OF FISHING</u>				
7. Catch Fleet Efficiency				
Monitoring of boat-days in the fishing grounds	25	100		1

Precision Ranging for

Fisheries - Stock Management - Year Class Spawning Success,  
Egg and Larval Survivability, and Effect of Fishing

Applies to  
Fig. 14

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>YEAR CLASS SPAWNING SUCCESS</u>					
1. Environmental Conditions in Spawning Areas					
Dynamic topography (current patterns)	300	10	$10^3$	10	5
<u>EGG AND LARVAL SURVIVABILITY</u>					
5. Departure from Suitable Water Mass Conditions					
Dynamic topography (current patterns)	300	10	$10^3$	10	5
<u>EFFECT OF FISHING</u>					

Microwave Radiometry for Fisheries - Stock Management - Year Class  
 Spawning Success, Egg and Larval Survivability, and Effect of Fishing

Applies to  
 Fig. 14

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>YEAR CLASS SPAWNING SUCCESS</u>							
1. Environmental Conditions in Spawning Areas							
Disposition of surface isohalines and isotherms	50	1000			0.5	0.5	7
Surface roughness	50	NA		NBN (0-12)			7
<u>EGG AND LARVAL SURVIVABILITY</u>							
5. Departure from Suitable Water Mass Conditions							
Disposition of surface isotherms & isohalines	50	1000			0.5	0.5	3
<u>EFFECT OF FISHING</u>							

Laser Depth Sounding for Fisheries - Stock Management - Year Class **Applies to**  
 Spawning Success, Egg and Larval Survivability, and Effect of Fishing **Fig. 14**

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>YEAR CLASS SPAWNING SUCCESS</u>				
1. Environmental Conditions in Spawning Areas Water depth	100		3	30
<u>EGG AND LARVAL SURVIVABILITY</u>				
4. Availability of Suitable Bottom Conditions Bottom topography	100		3	30
<u>EFFECT OF FISHING</u>				

Visible and Near IR Spectrometry/Imaging for  
 Fisheries - Information for Tactical Decisions -  
 Market Information, and Environmental Conditions

Applies to  
 Fig. 15

Applications	Spectral Range $\mu$	Spectral Bandwidth "	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST\%$	Observation Frequency Days
<b>MARKET INFORMATION</b>						
1. Port Accessibility						
Ice cover	.4-.7	Bd	1000	50	1-10	7 (1)
Shallow water color shift	.4-.7	.01	100	50	.1-1.0	30
Wave refractive patterns	.4-.7	Bd	50	50	1-10	30
3. Fishing Pressure						
Number of vessels on fishing grounds	.4-.7	Bd	25	100	1-10	7
<b>ENVIRONMENTAL CONDITIONS</b>						
5. Weather						
Atmospheric visibility	.4-.7	Bd	N.A.	50	.1-1.0	1
Cloud patterns and movements	.4-.7	Bd	$10^4$	50	1-10	1
Cloud height (oblique view and shadow displacement)	.4-.7	Bd	1000	50	1-10	1
6. Currents						
Current boundaries	.4-.7	.1	1000	100	.1-1.0	7
Lagrangian observations of surface objects	.4-.7	Bd	10-25	100	1-10	1
7. Sea Ice						
Location and trajectory of bergs and floes	.4-.7	Bd	25	100	1-10	1
8. Sea State						
Sea state (glitter analysis)	.4-.7	Bd	NA	glitter pattern	1-10	1

IR Radiometry/Imaging for  
Fisheries - Information for Tactical Decisions -  
Market Information, and Environmental Conditions

Applies to  
Fig. 15

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<b>MARKET INFORMATION</b>				
1. Port Accessibility Ice cover	1000	50		7 (1)
3. Fishing Pressure Number of vessels on fishing grounds	25	100		7
<b>ENVIRONMENTAL CONDITIONS</b>				
5. Weather Sea surface temperature (indicative of local precipitation)	1000	50	0.2	1
6. Currents Current boundaries (by sea surface temperature) Lagrangian observations of surface objects	100 10-25	100 100	0.5	7 1
7. Sea Ice Location and trajectory of bergs and floes	25	100		1

Radar Scatterometry/Imaging for  
Fisheries - Information for Tactical Decisions - Market  
Information, and Environmental Conditions

Applies to  
Fig. 15

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>MARKET INFORMATION</u>				
1. Port Accessibility				
Ice cover	1000	50	--	7 (1)
Wave refraction (indicative of shoals)	50	50	--	30
3. Fishing Pressure				
Number of vessels on fishing grounds	25	100	--	7
<u>ENVIRONMENTAL CONDITIONS</u>				
5. Weather				
Cloud patterns and movements	10 <sup>4</sup>	50		1
Precipitation	1000	50		1
7. Sea Ice				
Location and trajectory of bergs and floes	25	100		1
8. Sea State				
Sea state	NA	50	NBN (0-12)	1

**Precision Ranging for**

**Fisheries - Information for Tactical Decisions - Market Information, and Environmental Conditions**

**Applies to  
Fig. 15**

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>MARKET INFORMATION</u>					
<u>ENVIRONMENTAL CONDITIONS</u>					
5. Weather Depressions and elevations indicative of barometric high and low pressure cells	100	1	$10^3$	10	1
6. Currents Surface slopes associated with geostrophic flows	300	10	$10^3$	10	1
8. Sea State Swell height and wavelength	25	.002	5	25	1

Microwave Radiometry for Fisheries - Information for Tactical  
Decisions-Market Information, and Environmental Conditions

Applies to  
Fig. 15

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>MARKET INFORMATION</u> 1. Port Accessibility Ice cover	50	1000					7 (1)
<u>ENVIRONMENTAL CONDITIONS</u> 5. Weather							
Atmospheric thermal and humidity profiles	NA	NA					1
Precipitation (surface salinity and cloud emissivity)						0.5	1
Heat flux			.02				1
6. Currents Current boundaries (by sea surface temperature)	100	1000				0.5	7
8. Sea State Sea state	NA	50		NBN (0-12)			

Laser Depth Sounding for Fisheries - Information for Tactical  
Decisions - Market Information, and Environmental Conditions

Applies to  
Fig. 15

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>MARKET INFORMATION</u> 1. Port Accessibility Water depth	100		3	30
<u>ENVIRONMENTAL CONDITIONS</u>				

Visible and Near IR Spectrometry/Imaging for  
 Fisheries - Information for Tactical Decision-Fish Location and  
 Abundance, and Navigational and Catchability

Applies to  
 Fig. 16

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\%$	Observation Frequency Days
<b>INDICATIONS OF FISH LOCATION AND ABUNDANCE</b>						
1. Fleet Activities						
High resolution imagery of boats and wake patterns	.4-.7	Bd	25	100	1-10	7
2. Presence of Cover or Favorable Water Mass or Bottom Conditions						
Discolored water indicative of pollution	.4-1.2	.05	100	50	.01-.1	3
Turbidity	.4-.7	.1	100	50	.1-1.0	1
▲ Floating objects	.4-.7	Bd	25	50	1-10	3
Chlorophyll	.4-1.2	.05	1000	50	.1-1.0	3
▲ Shallow water color shift	.4-.7	.01	100	50	.1-1.0	30
Seaweed	.6-1.2	.02	100	50	.1-1.0	30
3. Presence of Associated Organisms						
Bird flocks	.4-.7	Bd	25	50	1-10	7
Porpoises	.4-.7	.05	25	50	.1-1.0	7
Forage organisms	.4-.7	.01	100	50	.01-.1	7
4. Bioluminescence						
Bioluminescence (fish schools)	.45-.55	.1	50	50	.01-.1	7
5. Oceanic Fronts						
Chlorophyll	.4-1.2	.05	1000	50	.1-1.0	3
Water color	.4-.7	.1	1000	50	.1-1.0	3
▲ Sea state (glitter analysis)	.4-.7	Bd	NA	glitter pattern	1-10	3
Cloud cover	.4-.7	Bd	1000	50	1-10	3
6. Upwellings						
Chlorophyll	.4-1.2	.05	1000	50	.1-1.0	3
Water color	.4-.7	.1	1000	50	.1-1.0	3
Sea state (glitter analysis)	.4-.7	Bd	NA	glitter pattern	1-10	3
Cloud cover	.4-.7	Bd	1000	50	1-10	3
<b>NAVIGATIONAL AND CATCHABILITY INFORMATION</b>						
6. Shoals						
Water depth	.4-.7	.01	100	50	.1-1.0	30
8. Thermocline Topography						
▲ Sea state (glitter analysis for surface internal waves & intensity of wind mixing)	.4-.7	Bd	50	100	1-10	7
9. Obstacles to Fishing						
Water color (pollution)	.4-1.2	.05	100	50	.01-.1	3
Oil slicks (glitter analysis)	.4-.7	Bd	100	50	1-10	1
Submerged objects	.4-.7	.01	10	50	.1-1.0	30
Water depth	.4-.7	.01	100	50	.1-1.0	2-19 30

IR Radiometry/Imaging for

Fisheries - Information for Tactical Decision - Fish Location  
and Abundance, and Navigational and Catchability

Applies to  
Fig. 16

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<b>INDICATIONS OF FISH LOCATION AND ABUNDANCE</b>				
5. Oceanic Fronts Sea surface temperature	1000	50		3
6. Upwellings Sea surface temperature	1000	50		3
<b>NAVIGATIONAL AND CATCHABILITY INFORMATION</b>				
7. Shoals Sea surface temperature (turbulence in lee of shoals)	100	50	1.0	30
8. Thermocline Topography ▲ Sea surface temperature	1000	50		7
Internal waves	300	50		7
9. Obstacles to Fishing Oil slick emissivity and temperature	100	50		1

# Radar Scatterometry/Imaging

Fisheries - Information for Tactical Decision - Fish Location and Abundance, and Navigational and Catchability

Applies to  
Fig. 16

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>INDICATIONS OF FISH LOCATION AND ABUNDANCE</u>				
<u>NAVIGATIONAL AND CATCHABILITY INFORMATION</u>				
7. Shoals Sea state (wave refraction patterns)	50	50	--	30
9. Obstacles to Fishing Sea state (oil slicks)	100	50	NBN (0-2)	1

Precision Ranging for  
 Fisheries - Information for Tactical Decision - Fish Location  
 and Abundance, Navigational and Catchability

Applies to  
 Fig. 16

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>INDICATIONS OF FISH LOCATION AND ABUNDANCE</u>					
<u>NAVIGATIONAL AND CATCHABILITY INFORMATION</u>					

Microwave Radiometry for Fisheries - Information for Tactical Decision-Fish Location and Abundance, and Navigational and Catchability Applies to Fig. 16

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency - cycles
<u>INDICATIONS OF FISH LOCATION AND ABUNDANCE</u>							
5. Oceanic Fronts							
Sea surface temperature	50	1000			.05		3
Sea surface salinity	50	1000				0.5	3
Cloud cover	50	1000					3
6. Upwellings							
Sea surface temperature	50	1000			0.5		3
Sea surface salinity	50	1000				0.5	3
Cloud cover	50	1000					3
<u>NAVIGATIONAL AND CATCH-ABILITY INFORMATION</u>							
7. Shoals							
Sea surface salinity	50	100				1.0	30
Sea surface temperature (turbulence in lee of shoals)	50	100			1.0		30
8. Thermocline Topography							
Sea surface temperature	50	1000					7
9. Obstacles to Fishing							
Sea surface temperature (oil slicks)	50	100					1

**Applies to  
Fig. 16**

2-24

Visible and Near IR Spectrometry/Imaging for  
 Fisheries - Improved Harvesting-Efficiency of Capture Methods,  
 Advantages of Unconventional Processing, and Benefits of  
 Aquaculture

Applies to  
 Fig. 17

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
RELATIVE EFFICIENCY OF VARIOUS CAPTURE METHODS <u>1. Gear Avoidance by Fish</u> Turbidity  ADVANTAGES ASSOCIATED WITH UNCONVENTIONAL PROCESSING APPROACHES  BENEFITS OF AQUACULTURE RELATIVE TO TRADITIONAL FISH HARVESTING MEANS	.4-.7	.05	100	50	.1-1.0	INT

IR Radiometry/Imaging for Fisheries - Improved Harvesting-Efficiency of Capture Methods, Advantages of Unconventional Processing, and Benefits of Aquaculture

Applies to Fig. 17

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>RELATIVE EFFICIENCY OF VARIOUS CAPTURE METHODS</u> 1. Gear Avoidance by Fish ▲ Sea surface temperature (as indicative of thermocline depth)	NA	10	0.5	14
<u>ADVANTAGES ASSOCIATED WITH UNCONVENTIONAL PROCESSING APPROACHES</u>				
<u>BENEFITS OF AQUACULTURE RELATIVE TO TRADITIONAL FISH HARVESTING MEANS</u>				

**Radar Scatterometry/Imaging for Fisheries-Improved Harvesting-  
Efficiency of Capture Methods, Advantages of Unconventional  
Processing, and Benefits of Aquaculture**

**Applies to  
Fig. 17**

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>RELATIVE EFFICIENCY OF VARIOUS CAPTURE METHODS</u>				
<u>ADVANTAGES ASSOCIATED WITH UNCONVENTIONAL PROCESSING APPROACHES</u>				
<u>BENEFITS OF AQUACULTURE RELATIVE TO TRADITIONAL FISH HARVESTING MEANS</u>				

Precision Ranging for Fisheries - Improved Harvesting-Efficiency  
of Capture Methods, Advantages of Unconventional Processing,  
and Benefits of Aquaculture

Applies to  
Fig. 17

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>RELATIVE EFFICIENCY OF VARIOUS CAPTURE METHODS</u>					
<u>ADVANTAGES ASSOCIATED WITH UNCONVENTIONAL PROCESSING APPROACHES</u>					
<u>BENEFITS OF AQUACULTURE RELATIVE TO TRADITIONAL FISH HARVESTING MEANS</u>					

**Microwave Radiometry for Fisheries-Improved Harvesting-Efficiency of Capture Methods, Advantages of Unconventional Processing and Benefits of Aquaculture** **Applies to Fig. 17**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<p><u>RELATIVE EFFICIENCY OF VARIOUS CAPTURE METHODS</u></p> <p>1. Gear Avoidance by Fish</p> <p>▲ Sea surface temperature (as indicative of thermocline depth)</p> <p><u>ADVANTAGES ASSOCIATED WITH UNCONVENTIONAL PROCESSING APPROACHES</u></p> <p><u>BENEFITS OF AQUACULTURE RELATIVE TO TRADITIONAL FISH HARVESTING MEANS</u></p>	10	NA			0.5		14

Laser Depth Sounding for Fisheries - Improved Harvesting-Efficiency
of Capture Methods, Advantages of Unconventional Processing,
and Benefits of Aquaculture

Applies to
Fig. 17

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<div> <div> RELATIVE EFFICIENCY OF VARIOUS CAPTURE METHODS </div> <div> ADVANTAGES ASSOCIATED WITH UNCONVENTIONAL PROCESSING APPROACHES </div> <div> BENEFITS OF AQUACULTURE RELATIVE TO TRADITIONAL FISH HARVESTING MEANS </div> </div>				

**Applies to  
Fig. 18**

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<u>ATMOSPHERIC CIRCULATION</u>						
1. Surface Wind Vectors and Fetch						
Smoke trails	.4-.7	Bd	100	100	1-10	1
Cloud patterns over relief features, cloud motion	.4-.7	"	$10^4$	50	"	"
Foam, white caps	.4-.7	.05	NA	20	.1-1	"
Sea state (glitter)	.4-.7	Bd	NA	glitter pattern	1-10	"
2. Vertical Motion						
Cloud mosaics	.4-.7	Bd	$10^4$	50	1-10	1
Oblique view of cloud height	"	Bd	$10^3$	horizon	1-10	"
3. Wind Profiles Aloft						
Cloud motion	"	"	$10^4$	50	1-10	"
▲ Jet vapor trails	"	"	300	50	"	"
<u>ATMOSPHERIC CONTENT</u>						
4. Water Vapor and Ice Profiles						
Clouds, visibility	.4-.7	"	$10^4$	50	"	"
5. Impurities						
Visibility (haze, gases, smoke)	.4-1.0	.05	$10^4$	50	.1-1	"
6. Air Density						
Clouds	"	Bd	$10^4$	50	1-10	"
7. Cloud Cover, Fog, Haze, Smoke						
Visibility	.4-.7	Bd	$10^4$	50	1-10	1
Cloud mosaics	.4-.7	"	"	"	1-10	"
Smoke	.4-1.0	.05	"	"	.1-1	"
<u>PHYSICAL STATE</u>						
8. Insolation/Albedo						
Reflected energy	.4-.7	Bd	NA	5	.1-1	"
10. Pressure/Density Structure						
Cloud formation at overlap of air masses	.4-.7	"	$10^4$	50	1-10	1

# IR Radiometry/Imaging for

Hazards - Historical Weather Information -  
Atmospheric Conditions

Applies to  
Fig. 18

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>ATMOSPHERIC CIRCULATION</u>				
2. Vertical Motion				
Cloud mosaics	10 <sup>4</sup>	50	NA	1
Indications of thermal rise or precipitation	10 <sup>4</sup>	50	NA	1
3. Wind Profiles Aloft				
Cloud motion	10 <sup>4</sup>	50	NA	1
<u>ATMOSPHERIC CONTENT</u>				
4. Water Vapor and Ice Profiles				
Clouds	10 <sup>4</sup>	50	NA	1
Cloud temperature	10 <sup>4</sup>	50	1	"
5. Impurities				
O <sub>3</sub> , CO <sub>2</sub> Absorption	NA	5	NA	1
<u>PHYSICAL STATE</u>				
8. Insolation/Albedo				
Reflected energy	NA	5	NA	1

Radar Scatterometry/Imaging for  
Hazards - Historical Weather Information -  
Atmospheric Conditions

Applies to  
Fig. 18

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>ATMOSPHERIC CIRCULATION</u>				
1. Surface Wind Vectors and Fetch Surface roughness	10 <sup>4</sup>	50	NBN(0-12)	1
2. Vertical Motion Cloud mosaics	10 <sup>4</sup>	50	NA	"
3. Wind Profiles Aloft Cloud motion	"	"	"	"
<u>ATMOSPHERIC CONTENT</u>				
4. Water Vapor and Ice Profiles Clouds	"	"	"	"
6. Air Density Cloud density	"	"	"	"
7. Cloud Cover, Fog, Haze, Smoke Cloud mosaics	"	"	"	"
<u>PHYSICAL STATE</u>				
				3-3

Precision Ranging for  
Hazards - Historical Weather Information -  
Atmospheric Conditions

Applies to  
Fig. 18

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>ATMOSPHERIC CIRCULATION</u>					
2. Vertical Motion					
Cloud height	50	2	$10^3$	$10^4$	1
Sea level variations due to surface pressure change	100	1	$10^3$	10	"
<u>ATMOSPHERIC CONTENT</u>					
4. Water Vapor and Ice Profiles					
Cloud height	50	2	$10^3$	$10^4$	"
<u>PHYSICAL STATE</u>					
10. Pressure Density Structure					
Sea level for surface pressure	100	1	$10^3$	10	"

**Applies to  
Fig. 18**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>ATMOSPHERIC CIRCULATION</u>							
1. Surface Wind Vector and Fetch							
Sea state	100	10 <sup>4</sup>		NBN(0-12)			1
Foam, white caps	100	10 <sup>4</sup>			.5		1
2. Vertical Motion							
Thermal profiles	5	NA			10%		1
3. Wind Profiles Aloft							
Cloud motion	50	10 <sup>4</sup>			1		1
<u>ATMOSPHERIC CONTENT</u>							
4. Water Vapor and Ice Profiles							
Clouds	50	10 <sup>4</sup>			1		1
Moisture profiles	5	NA					1
6. Air Density							
Clouds density	50	10 <sup>4</sup>			1		1
Moisture profiles	5	NA					1
7. Cloud Cover, Fog, Haze, Smoke							
Cloud mosaics	50	10 <sup>4</sup>			1		1
<u>PHYSICAL STATE</u>							
8. Insolation/Albedo							
Reflected energy	5	NA			.5		1
9. Temperature Profiles/							
Atmospheric Heat Flux							
Thermal profiles	5	NA			10%		1

Laser Depth Sounding for  
 Hazards - Historical Weather Information -  
 Atmospheric Conditions

Applies to  
 Fig. 18

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>ATMOSPHERIC CIRCULATION</u>				
None				
<u>ATMOSPHERIC CONTENT</u>				
None				
<u>PHYSICAL STATE</u>				
None				

**Fig. 19**

Applies to  
Fig. 19

3-8

Radar Scatterometry/Imaging for  
 Hazards-Improved Weather Forecasting-Air/Sea/Land Interaction  
 and Historical Weather Information

Applies to  
 Fig. 19

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>FORCING FUNCTIONS</u>				
<u>COUPLING MECHANISMS</u>				
4. Wind Stress Sea state and wind fetch	$10^4$	100	NBN(0-12)	1
5. Evaporation/Precipitation Cloud mosaics	$10^4$	50	cloud detection	1
6. Freezing/Melting Pack ice boundaries	$10^3$	100	ice detection	30
				3-9

Precision Ranging for  
 Hazards-Improved Weather Forecasting-Air/Sea/Land Interaction  
 and Historical Weather Information

Applies to  
 Fig. 19

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>FORCING FUNCTIONS</u>					
<u>COUPLING MECHANISMS</u>					
4. Wind Stress Wave profiles for sea state	5	.002	5	25	1
5. Evaporation/Precipitation Cloud height	100	10	$10^3$	$10^4$	1
6. Freezing/Melting Pack ice thickness	50	1.0	$10^3$	10	30
					3-10

Microwave Radiometry for  
Hazards-Improved Weather Forecasting-Air/Sea/Land Interaction  
and Historical Weather Information

Applies to  
Fig. 19

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>FORCING FUNCTIONS</b>							
1. Insolation							
Microwave albedo	50	NA	10%				1
<b>COUPLING MECHANISMS</b>							
4. Wind Stress							
Sea state and wind fetch	100	10 <sup>4</sup>		NBN(0-12)			1
5. Evaporation/Precipitation							
Atmospheric thermal and humidity profiles	10	NA			10%		1
Surface temperature	50	1000			0.5		1
Heat flux	60-120	NA	0.2				1
Cloud mosaics	100	10 <sup>4</sup>					1
6. Freezing/Melting							
Surface temperature and salinity	100	10 <sup>5</sup>			±0.5	±0.5	14
Atmospheric thermal profiles	10	NA			10%		1
Pack ice thickness and boundaries	100	10 <sup>3</sup>			0.5		30

Laser Depth Sounding for  
Hazards-Improved Weather Forecasting-Air/Sea/Land Interaction  
and Historical Weather Information

Applies to  
Fig. 19

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>FORCING FUNCTIONS</u> None				
<u>COUPLING MECHANISMS</u> None				

Visible and Near IR Spectrometry/Imaging for  
 Hazards - Improved Weather Forecasting-  
 Air/Sea/Land Interaction and Historical Weather Information

Applies to  
 Fig. 20

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>RESPONSE PATTERNS</b>						
1. Estuarine Circulation Turbidity patterns	.4-.7	.1	$10^3$	25	.1-1	Int.
2. Ekman Transport Trajectories of floating objects	"	Bd.	10	10	.1-1	1
Sea state, wind fetch, (glitter analysis)	"	"	NA	glitter pattern	1-10	1
▲ Wave directional spectrum (wave pattern)	"	"	200	100	1-10	1
4. Atmospheric Motion Sea state and wind fetch (glitter)	"	"	NA	glitter pattern	1-10	1
▲ Wave directional spectrum (wave pattern)	"	"	200	100	1-10	1
Cloud trajectories and mosaics	"	"	$10^3$	50	1-10	1
Cloud height (oblique view)	"	"	$10^3$	horizon	1-10	1
5. Geostrophic Flow Floating object trajectories	"	"	10	100	.1-1	1
7. Stratification Surface-breaking internal waves (roughness)	.4-.7	0.1	300	100	.1-1	5
8. Barometric Loading Cloud mosaics indicative of high and low pressure cells	.4-.7	Bd.	$10^4$	100	1-10	1
Cloud height (oblique view)	"	"	$10^3$	horizon	1-10	1
9. Surface and Internal Wave Generation Surface-breaking internal wave direction and wavelength	.4-.7	0.1	300	100	.1-1	5
Sea state, wind fetch, glitter	.4-.7	Bd.	NA	glitter pattern	1-10	1
Surface wave directional spectrum	.4-.7	"	200	100	1-10	1
Cloud patterns indicative of storms	.4-.7	"	$10^4$	50	1-10	1
10. Diurnal Tides Width of intertidal zone	"	"	$20^3$	20	10	7
Turbidity patterns	"	.05	$10^3$	25	.1-1	1

Visible and Near IR Spectrometry/Imaging for  
 Hazards - Improved Weather Forecasting -  
 Air/Sea/Land Interaction and Historical Weather Information

Applies to  
 Fig. 20

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>RESPONSE PATTERNS (CONT'D)</b>						
11. Upwellings, Convergences, Divergences						
Surface color contrasts, chlorophyll	.4-.7	.03	10 <sup>3</sup>	100	.01-0.1	14
Windrows of debris and foam	"	.5	50	50	.1-1	14
Cloud patterns	"	Bd.	10	50	1-10	14
<b>ENERGY DISSIPATION</b>						
12. Surf						
Surf zone width	.4-.7	Bd.	20	25	1-10	7
Bottom topography	.4-.7	.01	100	100	.1-1	30
Swell wavelength	.4-.7	Bd.	50	20	1-10	7
Spacing of wave groups	.4-.7	"	100	50	1-10	7
13. Current and Wind Frictional Drag						
Sea state and wind fetch (glitter)	.4-.7	"	NA	glitter pattern	1-10	7

IR Radiometry/Imaging for  
Hazards - Improved Weather Forecasting Air/Sea/Land  
Interaction and Historical Weather Information

Applies to  
Fig. 20

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<b>RESPONSE PATTERNS</b>				
1. <u>Estuarine Circulation</u>				
Surface thermal patterns	10 <sup>4</sup>	25	.5	3
2. Deep Water Circulation				
Surface temperature in vicinity of submerging water masses	10 <sup>3</sup>	50	1	3
3. Ekman Transport				
Trajectories of floating objects	10	20	NA	1
4. <u>Atmospheric Motion</u>				
Cloud trajectories and mosaics	10 <sup>4</sup>	50	NA	1
5. <u>Geostrophic Flow</u>				
Current thermal boundaries	10 <sup>3</sup>	100	.5	7
Floating object trajectories	10	20	NA	1
7. Stratification				
Surface-breaking internal waves	300	150	.1	7
8. <u>Barometric Loading</u>				
Cloud mosaics	10 <sup>4</sup>	50	NA	1
9. Surface and Internal Wave Generation				
Surface-breaking internal wave direction and wavelength	300	150	NA	7
Storm clouds	10 <sup>4</sup>	50	NA	1
11. <u>Upwellings, Convergences, Divergences</u>				
Surface temperature	10 <sup>3</sup>	25	1	3
Cloud patterns	10 <sup>4</sup>	50	NA	1
<b>ENERGY DISSIPATION</b>				
				3-15

Radar Scatterometry/Imaging for  
Hazards - Improved Weather Forecasting - Air/Sea/Land  
Interaction and Historical Weather Information

Applies to  
Fig. 20

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<b>RESPONSE PATTERNS</b>				
3. Ekman Transport				
▲ Wave directional spectrum	NA	100	10%	1
4. Atmospheric Motion				
Cloud trajectories and mosaics	10 <sup>4</sup>	50	"	1
5. Geostrophic Flow				
Floating object trajectories	10	20	object detection	1
7. Stratification				
Surface-breaking internal waves (roughness)	300	100	NBN(0-2)	3
8. Barometric Loading				
Cloud mosaics	10 <sup>4</sup>	50	NA	1
9. Surface and Internal Wave Generation				
Sea state, wind fetch	10 <sup>4</sup>	100	NBN(3-12)	1
Wave directional spectrum	NA	100	10%	1
Storm clouds	10 <sup>4</sup>	50	NA	1
Surface-breaking internal wave direction and wavelength	300	100	NBN(0-2)	1
11. Upwellings, Convergences, Divergences				
Windrows of debris and foam	10 <sup>2</sup>	100	NA	5
Cloud patterns	10 <sup>4</sup>	50	NA	1
<b>ENERGY DISSIPATION</b>				
12. Surf				
Swell wavelength, spacing of wave groups	100	25	NA	3
13. Current and Wind Frictional Drag				
Sea state and wind fetch	10 <sup>4</sup>	100	NBN(0-12)	3

Precision Ranging for  
Hazards - Improved Weather Forecasting - Air/Sea/Land  
Interaction and Historical Weather Information

Applies to  
Fig. 20

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<b>RESPONSE PATTERNS</b>					
<b>4. Atmospheric Motion</b>					
Cloud height	NA	NA	$10^3$	$10^4$	1
<b>5. Geostrophic Flow</b>					
Surface slope	300	10	$10^3$	10	Int.
<b>8. Barometric Loading</b>					
Surface slope	100	1	$10^3$	$10^4$	1
Cloud height	50	2	$10^3$	$10^4$	1
<b>9. Surface and Internal Wave Generation</b>					
Wave profiles for sea state	25	.002	5	25	1
<b>10. Diurnal Tides</b>					
Tidal amplitude	100	5	$10^3$	5	1
<b>ENERGY DISSIPATION</b>					
<b>12. Surf</b>					
Swell amplitude, wavelength, spacing of wave groups	25	.002	5	25	1

Applies to  
Fig. 20

Interaction and Historical Weather Information							
Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>RESPONSE PATTERNS</b>							
1. Estuarine Circulation Surface thermal and salinity patterns	25	10 <sup>4</sup>			.5	1	3
2. Deep Water (Thermocline Circulation ▲ Surface temperature and salinity in vicinity of submerging water masses	100	10 <sup>3</sup>			.5	.5	14
4. Atmospheric Motion Cloud trajectories and mosaics	50	10 <sup>4</sup>			NA	NA	1
5. Geostrophic Flow Current thermal and salinity boundaries	300	10 <sup>4</sup>			.5	.5	7
6. Water Column Convective Return							
Atmospheric thermal profiles	10	NA			10%		1
8. Barometric Loading							
Atmospheric thermal and humidity profiles	10	NA			10%		1
Cloud mosaics	50	10 <sup>4</sup>					1
9. Surface and Internal Wave Generation							
Sea state, wind fetch	300	10 <sup>4</sup>		NBN(0-12)			1
Storm clouds	200	10 <sup>4</sup>					1
11. Upwellings, Convergences, Divergences							
Surface temperature and salinity	50	10 <sup>3</sup>			1	1	7
Cloud patterns	50	10 <sup>4</sup>					1
<b>ENERGY DISSIPATION</b>							
13. Current and Wind Frictional Drag							
Sea state and wind fetch	100	NA		NBN(0-12)			1
14. Heat Radiation Heat flux	50-100	NA	0.2				10

**Applies to  
Fig. 20**

**3-19**

**Visible and Near IR Spectrometry/Imaging for  
Hazards - Location and Character of  
Navigational Hazards**

**Applies to  
Fig. 21**

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>NATURAL</b>						
1. High Winds Sea state (glitter analysis)	"	"	NA	glitter pattern	1-10	1
Cloud drift	"	"	$10^4$	50	"	"
2. High Seas Sea state (glitter analysis)	"	"	NA	glitter pattern	"	"
△ 4. Kelp and Sargassum ▲ Surface vegetation	.4-1.2	.05	50	25	.1-1	30
Variations in shallow water color	.4-.7	.01	300	25	.1-1	30
5. Fog Atmospheric visibility	.4-.7	.1	$10^4$	100	1-10	1
6. Shoals Color indications of bottom discontinuities	.4-.6	0.01	100	25	.1-1	30
Sea state (wave refractive patterns)	"	Bd	200	100	1-10	"
7. Sea Ice Mapping of size and extent of ice fields	.4-.7	Bd	$10^3$	50	1-10	7
<b>ARTIFICIAL</b>						
9. Marine Engineering Structures Color indications of bottom discontinuities	.4-.6	.03	300	25	.1-1	30
△ 10. Offshore Dumping ▲ Color Indications of bottom discontinuities	.4-.6	.03	300	25	.1-1	30
△ 11. Shipwrecks ▲ Color Indications of bottom discontinuities	.4-.6	.03	300	25	.1-1	30
△ 13. Other Ships ▲ Visible sighting	.4-.7	Bd	25	5	1-10	.05
						3-20

# IR Radiometry/Imaging for

Hazards - Location and Character of Navigational Hazards

Applies to  
Fig. 21

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>NATURAL</u>				
1. High Winds Cloud drift	10 <sup>4</sup>	50	NA	1
5. Fog Temperature profile	10 <sup>4</sup>	100	2	1
7. Sea Ice Pack ice boundaries	1000	50	-	7(1)
Bergs and floes	25	50	-	1
8. Icing Conditions Temperature profile	10 <sup>5</sup>	100	1	1
<u>ARTIFICIAL</u>				
△ 10. Off Shore Dumping ▲ Emissivity changes due to slicks	100	15	.1	2
△ 13. Other Ships ▲ Temperature discontinuities	100	5	.1	.05

Radar Scatterometry/Imaging for  
Hazards - Location and Character of  
Navigational Hazards

Applies to  
Fig. 21

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>NATURAL</u>				
1. High Winds Directional spectrum of sea and swell	NA	50	10°	1
Overall surface roughness	NA	10	NBN(0-12)	"
Radar-cloud drift and clear air turbulence waves	10 <sup>4</sup>	50	NA	"
2. High Seas Overall surface roughness	10 <sup>5</sup>	100	NBN(3-12)	"
3. Long Period Swells Swell wavelength	10 <sup>3</sup>	50	NA	"
△ 4. Kelp and Sargassum ▲ Overall surface roughness (imaging)	100	20		30
6. Shoals Overall surface roughness (imaging)	200	50	NBN(3-12)	30
7. Sea Ice Pack ice boundaries	10 <sup>3</sup>	50		7(1)
Bergs and floes	25	50		1
8. Icing Conditions Overall surface roughness (scatterometry)	10 <sup>5</sup>	100	NBN(3-12)	1
<u>ARTIFICIAL</u>				
9. Marine Structures ▲ Roughness indications of submerged structures	100	10	NBN(3-12)	30
△ 10. Offshore Dumping ▲ Roughness indications of submerged structures	100	10	NBN(3-12)	30
△ 11. Shipwrecks ▲ Roughness indications of submerged structures	100	10	NBN(3-12)	30
△ 13. Other Ships ▲ Ship Tracking	25	50	ship detection	.05
				3-22

Precision Ranging for  
Hazards - Location and Character of Navigational Hazards

Applies to  
Fig. 21

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>NATURAL</u>					
3. Long Period Swells Wave profiling	5	.004	10	25	1
<u>ARTIFICIAL</u>					

**Microwave Radiometry for**  
**Hazards - Location and Character of Navigational Hazards**

**Applies to**  
**Fig. 21**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>NATURAL</b>							
1. High Winds Surface roughness	50	10 <sup>4</sup>		NBN(3-12)			1
2. High Seas Surface roughness	50	10 <sup>4</sup>		NBN(3-12)			1
Δ 4. Kelp & Sargassum Surface roughness	50	25		NBN(0-2)			30
5. Fog Humidity profile	50	10 <sup>4</sup>			2		1
6. Shoals Surface roughness	25	100		NBN(3-12)			30
7. Sea Ice Pack ice boundaries	50	1000					7(1)
Ice thickness	50	1000					1
8. Icing Conditions Sea state	300	10 <sup>5</sup>		NBN(3-12)			1
Humidity profile	300	10 <sup>5</sup>					1
Temperature	300	10 <sup>5</sup>			.5		1
<b>ARTIFICIAL</b>							
9. Marine Eng. Structures ▲ Surface roughness	20	200		NBN(0-12)			30
Δ 10. Offshore Dumping ▲ Salinity changes	15	100				1	2

# Laser Depth Sounding for

Hazards - Location and Character of Navigational Hazards

Applies to  
Fig. 21

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>NATURAL</u>				
6. Shoals Bottom topography	300	300	3	30
<u>ARTIFICIAL</u>				
9. Marine Structures Bottom topography	50	50	5	30
△ 10. Offshore Dumping ▲ Bottom topography	50	50	5	30
△ 11. Shipwrecks ▲ Bottom topography	50	50	5	30

Visible and Near IR Spectrometry/Imaging for  
Hazards - Advanced Warning of Hazards

Applies to  
Fig. 22

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
2. Hurricanes Sea state discontinuities	.4-.7	broadband	NA	glitter pattern	1-10	1
3. Storm Surges Sea state Glitter analysis	.4-.7	"	NA	glitter pattern	1-10	1
4. High Seas Sea state Glitter analysis	.4-.7	broadband	NA	glitter pattern	1-10	1
▲ Foam	.4-.7	.05	"	5	.1-1	1
5. Biological Infestations: Color variations in estuaries and coastal waters (sea urchins destroying kelp, etc.)	.6-1.0	.02	50	50	.1-1	14
6. Toxic Spills Surface slicks (glitter) (color) Turbidity	.4-.7 .3-.8 .4-.7	Bd 0.05 0.03	300 300 500	glitter pattern 50 50	1-10 .05-1 .01-.1	Inc. Inc.
7. Oil Spills Surface slicks (glitter) (color) ▲ Turbidity	.4-.7 .3-.8 .4-.7	Bd 0.05 0.03	300 300 500	glitter pattern 50 50	1-10 .05-1 .01-.1	Inc. Inc. Inc.
8. Ice Fields Reflectivity of visible energy	.4-.7	broadband	$10^3$	50	1-10	7
9. Ice Bergs Reflectivity of visible energy	.4-.7	"	25	20	1-5	1
▲ 10. Debris ▲ Visible large surface deposits	.4-1.0	0.05	100	50	.1-1	7

IR Radiometry/Imaging for  
Hazards - Advanced Warning of Hazards

Applies to  
Fig. 22

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
6. Toxic Spills Isothermal mapping of spill	300	20	0.1	Inc.
7. Oil Spills Isothermal mapping of spill	300	20	0.1	Inc.
8. Ice Fields Temperature discontinuities	1000	50	1.0	7
9. Ice Bergs Temperature discontinuities	25	50	1.0	7

Radar Scatterometry/Imaging for  
Hazards - Advanced Warning of Hazards

Applies to  
Fig. 22

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
1. Tsunamis				
2. Hurricanes				
Surface roughness	$10^4$	50	NBN(3-12)	1
Cloud cover	$10^4$	50	NA	1
4. High Seas				
Overall surface roughness	$10^5$	100	NBN(3-12)	1
5. Biological Infestations				
Roughness indications	$10^3$	50	NBN(0-2)	Inc.
6. Toxic Spills				
Roughness indications	$10^3$	50	NBN(0-2)	Inc.
7. Oil Spills				
Roughness indications of surface presence	$10^3$	50	NBN(0-2)	Inc.
8. Ice Fields				
Changes in surface roughness				
9. Ice Bergs				
Changes in surface roughness	25	50	object detection	
△10. Debris				
▲ Changes in surface roughness	25	50	object detection	

Precision Ranging for  
Hazards - Advanced Warning of Hazards

Applies to  
Fig. 22

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
1. Tsunamis					
2. Hurricanes Geostrophic variations	50	1	$10^3$	10	Inc.
3. Storm Surges ▲ Barometric pressure in the vicinity of local generation Wave profiling	50 5	1 .002	$10^3$ 5	10 25	Inc. Inc.

Microwave Radiometry for  
Hazards - Advanced Warning of Hazards

Applies to  
Fig. 22

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
2. Hurricanes Surface roughness	50	10 <sup>4</sup>		NBN(3-12)			1
3. Storm Surges ▲ Surface roughness	50	10 <sup>4</sup>		NBN(3-12)			1
4. High Seas Surface roughness	100	10 <sup>5</sup>		NBN			1
6. Toxic Spills Isohaline and iso-thermal mapping to determine disposition of spill	25	10 <sup>3</sup>			0.1	1.0	Inc.
7. Oil Spills Isohaline and iso-thermal mapping to determine disposition of spill	25	10 <sup>3</sup>			0.1	1.0	Inc.
8. Ice Fields Decrease in salinity due to sea ice Temperature	100 100	10 <sup>3</sup> 10 <sup>3</sup>			1	1.0	7 7

**Applies to  
Fig. 22**

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days

3-31

Visible and Near IR Spectrometry/Imaging for  
Cartography, Etc. - Area Exploitation

Applies to  
Fig. 23

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>ACCURATE AND CURRENT MAPS AND CHARTS</b>						
1. <u>Urban &amp; Industrial Growth</u>						
Shoreline alterations	.4-.7	Bd.	100	50	1-10	60
Manmade structures	.4-.7	Bd.	10	10	.1-1	60
Shipping	.4-.7	Bd.	10-20	50	.1-1	INT (30)
2. Marine Construction & Dredging						
Turbidity	.4-.7	.1	100	50	.1-1	INT (30)
New structures	.4-.7	Bd.	10	10	.1-1	60
Shallow water color shift	.4-.7	.01	100	50	.1-1	INT (30)
3. Agriculture Activities						
Crop identity, quality, quantity	.4-1.2	.05	100	50	.01-.1	14
Soil quality	.4-.8	.05	1000	50	.1-1	30
<b>COASTAL SPACE QUALITY</b>						
4. Sedimentation Rate						
Turbidity (littoral drift, rip currents)	.4-.7	.1	10-50	10	.1-1	INT (30)
Shallow water color shift	.4-.7	.01	1000	50	.1-1	30
5. Estuarine & Nearshore Circulation Patterns						
Turbidity	.4-.7	.1	100	50	.1-1	INT (30)
Dye patterns	.4-.7	.01	50	10	.01-1	1/24
6. Beach Character						
Beach width	.4-.7	Bd.	10	50	10	INT (14)
Offshore sand deposits	.4-.7	.01	1000	50	.1-1	INT (14)
Intertidal zone width	.4-.7	Bd.	5-10	50	10	INT (14)
Shallow water color shift	.4-.7	.01	1000	50	.1-1	INT (14)
7. Natural Hazards						
Discolored water (due to red tides, natural oil seeps)	.4-1.2	.05	100	50	.01-.1	INT (1)
Turbidity (as indicator of strong currents)	.4-.7	.1	10-50	10	.1-1	INT (14)
8. Water Quality						
Turbidity	.4-.7	.05	1000	50	.1-1	INT (30)
Water discoloration	.4-.7	.02	100	50	.01-.1	INT (30)
Aquatic vegetation	.6-1.2	.02	100	50	.1-1	INT (30)
9. Terrain Stability						
Surface structural geology	.4-.7	Bd.	100	50	1-10	INT (1 Year)

IR Radiometry/Imaging for  
Cartography, Etc. = Area Exploitation

Applies to  
Fig. 23

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<b>ACCURATE AND CURRENT MAPS AND CHARTS</b>				
1. Urban and Industrial Growth				
Shoreline alterations	100	50		60
Man-made structures	10	10		60
Shipping activities	10-20	50		INT (30)
2. Marine Construction and Dredging				
New structures	10	10		60
<b>COASTAL SPACE QUALITY</b>				
4. Sedimentation Rate				
Littoral current patterns	10-50	10	.1	INT (30)
5. Estuarine and Nearshore Circulation Patterns				
Sea surface temperature	100	50	.2	INT (30)
6. Beach Character				
Beach width	10	50		INT (14)
Intertidal zone width	5-10	50		INT (14)
7. Natural Hazards				
Surface temperature	10-50	10	.2	INT (14)
8. Water Quality				
Surface temperature	1000	100	1	INT (30)
Thermal pollution	10-50	10	.2	INT (30)
9. Terrain Stability				
Surface structural geology	100	50		INT (1 Year)

Radar Scatterometry/Imaging for  
Cartography, Etc. - Area Exploitation

Applies to  
Fig. 23

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>ACCURATE AND CURRENT MAPS AND CHARTS</u>				
1. Urban and Industrial Growth				
Shoreline alterations	100	50		60
Manmade structures	10	10		60
Shipping activity	10-20	50		INT (30)
2. Marine Construction and Dredging				
Surface roughness changes due to new structures	1000	50	NBN(3-12)	INT (30)
<u>COASTAL SPACE QUALITY</u>				
6. Beach Character				
Beach width	10	50	10 feet	INT (14)
Intertidal zone width	5-10	50	10 feet	INT (14)
9. Terrain Stability				
Surface structural geology	100	50		INT (1 Year)

Precision Ranging for  
Cartography, Etc. - Area Exploitation

Applies to  
Fig. 23

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>ACCURATE AND CURRENT MAPS AND CHARTS</u>					
<u>COASTAL SPACE QUALITY</u>					
5. Estuarine and Nearshore Circulation Patterns					
Tidal amplitude	100	5	$10^3$	10	INT (14)
6. Beach Character					
Beach height	100	5	$10^3$	10	INT (14)
Tidal amplitude	100	5	$10^3$	10	INT (14)
9. Terrain Stability					
Land shifts	100	1	10	50	INT (1 Year)

Microwave Radiometry for  
Cartography, Etc. - Area Exploitation

Applies to  
Fig. 23

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
ACCURATE AND CURRENT MAPS AND CHARTS							
1. Urban and Industrial Growth Saline and thermal alterations	50	1000			.5	.5	60
COASTAL SPACE QUALITY							
4. Sedimentation Rate Estuarine circulation	10	10-50			.2	.2	INT(30)
5. Estuarine and Nearshore Circulation Patterns Surface salinity (for tracing river effluent)	100	50				.5-1.0	INT(30)
7. Natural Hazards Surface temperature	10	10-50			.2		INT(14)
8. Water Quality Surface salinity	100	1000				1.0	INT(30)
Surface temperature	100	1000			1.0		INT(30)

Laser Depth Sounding for  
Cartography, Etc. - Area Exploitation

Applies to  
Fig. 23

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>ACCURATE AND CURRENT MAPS AND CHARTS</u>				
2. Marine Construction and Dredging Bottom topography	50		1	INT (30)
<u>COASTAL SPACE QUALITY</u>				
4. Sedimentation Rate Bottom topography	1000		1	INT (30)
6. Beach Character Nearshore bottom topography	1000		3	INT (14)

Visible and Near IR Spectrometry/Imaging for  
Cartography - Resources Management

Applies to  
Fig. 24

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>LOCATION, ACCESSIBILITY, QUALITY, AND DEGREE OF EXPLOITATION OF MINERAL DEPOSITS</b>						
<b>1. Mineral Deposits</b>						
Bottom color (as index of composition)	.4-.7	.05	100	10	.1-1.0	30-60
Natural petroleum slicks (glitter)	.4-.7	Bd	300	glitter pattern	1-10	INC (60)
(color)	.3-.8	.05	300	50	.05-1.0	INC (60)
<b>IDENTIFICATION OF POTENTIAL ENERGY SOURCES</b>						
<b>2. Tidal and Surf Action</b>						
▲ Turbidity	.4-.7	.1	100	50	.1-1.0	INT (60)
▲ Width of surf zone	.4-.7	Bd.	10	50	1-10	INT (60)
▲ Color shift due to depth	.4-.7	.02	100	50	.1-1.0	INT (60)
<b>4. Rivers</b>						
▲ Turbidity indications of flow rates at river mouth	.4-.7	.1	100	50	.1-1.0	INT (60)
● Local topography and geological composition	.4-.7	.05	100	50	.1-1.0	INT (60)
<b>5. Consistent Wind Patterns</b>						
▲ Sea state (glitter analysis)	.4-.7	Bd.	N.A.	glitter pattern	1-10	INT (60)
<b>6. Ocean Currents</b>						
▲ Trajectories of floating objects	.4-.7	Bd	100	50	1-10	INT(1/2-1)
Current boundaries	.4-.7	.1	1000	50	.1-1.0	INT(14)
Sediment patterns	.4-.7	.1	1000	50	.1-1.0	INT(14)
<b>EXISTING AND POTENTIAL FRESH WATER SOURCES</b>						
<b>7. Standing Water Reserves</b>						
Areal extent of bodies of fresh water	.4-.7	Bd	100	50	1-10	7
Water depth (spectral shift)	.4-.7	.02	100	50	.1-1.0	7
Water discoloration (due to pollution or plankton bloom)	.4-1.2	.05	100	50	.01-.1	14
<b>8. Frozen Water Reserves</b>						
▲ Snow and glacier boundaries (areal extent)	.4-.7	Bd	1/2 mile	10	1-10	7 (1)
● Snow pack albedo	.4-.7	Bd	--	10	2-5% accuracy	7 (1)
<b>9. Nearshore Springs</b>						
Chlorophyll	.4-1.2	.05	100	50	.1-1.0	INC (60)
						4-7

Visible and Near IR Spectrometry/Imaging for  
Cartography - Resources Management

Applies to  
Fig. 24

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>ASSESSMENT AND MANAGEMENT OF MIGRATORY OR NONMIGRATORY LIVING RESOURCES</b>						
10. Concentration of Marine Organisms						
Chlorophyll	.4-1.2	.05	1000	50	.1-1.0	3
Turbidity	.4-.7	.1	1000	50	.1-1.0	1
Water discoloration (due to pollution)	.4-1.2	.05	100	50	.01-.1	7
Surface roughness (seaweed boundaries)	.4-.7	Bd	100	50	1-10	30

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy %	Observation Frequency Days
<u>LOCATION, ACCESSIBILITY, QUALITY, AND DEGREE OF EXPLOITATION OF MINERAL DEPOSITS</u>				
1. Mineral Deposits				
Natural petroleum slicks	300	50	0.1	INC (60)
<u>IDENTIFICATION OF POTENTIAL ENERGY SOURCES</u>				
△ 3. Geothermal Heat				
▲ Land temperature	300	50	1.0	INT (1/2 Year)
△ 4. Rivers				
▲ Isotherm mapping at river mouth	100	50	0.5	INT (14)
△ 5. Consistent Wind Patterns				
Areas where wind mixing disrupts surface thermal structure	1000	100	0.5	INT (14)
△ 6. Ocean Currents				
Lagrangian observations on floating objects	100	50	1.0	INT (1/2-1)
Current boundaries	1000	50	0.5	INT (14)
<u>EXISTING AND POTENTIAL FRESH WATER SOURCES</u>				
7. Standing Water Reserves				
Areal extent of bodies of fresh water	100	50	2.0	7
8. Frozen Water Reserves				
Snow and glacier boundaries (areal extent)	~1/2 mile	10	1.0	7 (1)
▲ Snow pack albedo	--	10	1.0	7 (1)
9. Nearshore Springs				
Sea surface temperature	50	50	0.2	INC (60)
<u>ASSESSMENT AND MANAGEMENT OF MIGRATORY OR NON-MIGRATORY LIVING RESOURCES</u>				
10. Concentration of Marine Organisms				
Disposition of isotherms exceeding tolerance range of important species	1000	50	0.5	7

Radar Scatterometry/Imaging for  
Cartography - Resources Management

Applies to  
Fig. 24

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>LOCATION, ACCESSIBILITY, QUALITY, AND DEGREE OF EXPLOITATION OF MINERAL DEPOSITS</u>				
1. Mineral Deposits				
Surface roughness (natural petroleum slicks)	300	50		INC (60)
<u>IDENTIFICATION OF POTENTIAL ENERGY SOURCES</u>				
△ 2. Tidal and Surf Action				
▲ Nearshore sea state	100	50	NBN(3-12)	INT (14)
△ 4. Rivers				
▲ Local topography	100	50		INT (1 Year)
△ 5. Consistent Wind Patterns				
▲ Sea state	N.A.	10	NBN(0-12)	INT (14)
△ 6. Ocean Currents				
▲ Lagrangian observations on floating objects	100	50		INT (1/2-1)
<u>EXISTING AND POTENTIAL FRESH WATER SOURCES</u>				
7. Standing Water Reserves				
Areal extent of bodies of fresh water	100	50		7
8. Frozen Water Reserves				
Snow and glacier boundaries (areal extent)	~1/2 mile	10		7
<u>ASSESSMENT AND MANAGEMENT OF MIGRATORY OR NON-MIGRATORY LIVING RESOURCES</u>				
10. Concentrations of Marine Organisms				
Surface roughness (for delineation of seaweed boundaries)	100	50		30

Precision Ranging for  
Cartography - Resources Management

Applies to  
Fig. 24

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>LOCATION, ACCESSIBILITY, QUALITY, AND DEGREE OF EXPLOITATION OF MINERAL DEPOSITS</u>					
1. Mineral Deposits					
▲ Average tidal amplitude	100	5	10 <sup>3</sup>	10	INT (7)
<u>IDENTIFICATION OF POTENTIAL ENERGY SOURCES</u>					
Δ 2. Tidal and Surf Action					
▲ Tidal amplitude (local)	100	5	10 <sup>3</sup>	10	INT (7)
Wave profiles		5-10 ft.	1-2	50	INT (14)
Δ 5. Consistent Wind Patterns					
▲ Persistent slopes maintained by coastal winds	300	10	10 <sup>3</sup>	10	INT (14)
Δ 6. Ocean Currents					
▲ Sea surface slopes accompanying geostrophic flows	300	10	10 <sup>3</sup>	10	INT (14)
<u>EXISTING AND POTENTIAL FRESH WATER SOURCES</u>					
7. Standing Water Reserves					
Water level in lakes, reservoirs, rivers	N.A.	1	100	25	7
<u>ASSESSMENT AND MANAGEMENT OF MIGRATORY OR NONMIGRATORY LIVING RESOURCES</u>					

**Microwave Radiometry for  
Cartography - Resources Management**

**Applies to  
Fig. 24**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>LOCATION, ACCESSIBILITY, QUALITY, AND DEGREE OF EXPLOITATION OF MINERAL DEPOSITS</b>							
<b>1. Mineral Deposits</b>							
Natural petroleum slicks	50	300					INC (60)
<b>IDENTIFICATION OF POTENTIAL ENERGY SOURCES</b>							
<b>2. Tidal &amp; surf action</b>							
Nearshore sea state	50	100		NBN(3-12)			INT (14)
<b>3. Geothermal Heat</b>							
Land temperature	50	300			1.0		INT (1/2 Year)
<b>4. Rivers</b>							
Isotherm and isohaline mapping at river mouth	50	100			0.5	0.5	INT (14)
<b>5. Consistent Wind Patterns</b>							
Areas where wind mixing disrupts surface tempera- ture, salinity, heat flux and sea state	100	1000	0.2		0.5	0.5	INT (14)
<b>6. Ocean Currents</b>							
Current boundaries (temperature, and salinity)	50	1000			0.5	0.5	INT (14)
<b>EXISTING AND POTENTIAL FRESH WATER SOURCES</b>							
<b>7. Standing Water Reserves</b>							
Surface salinity	50	1000				5.0	INT (30)
Areal extent	50	100			2.0		7
<b>8. Frozen Water Reserves</b>							
Snow and glacier boundaries (areal extent)	10	~1/2 mile			2.0		7 (1)
Snow pack albedo	10	--	2-5%		1.0		7 (1)
<b>9. Nearshore Springs</b>							
Surface salinity	50	50				5.0	INC (60)
Temperature	50	50			0.2		INC (60)
							4-12

**Microwave Radiometry for  
Cartography - Resources Management**

**Applies to  
Fig. 24**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
ASSESSMENT AND MANAGEMENT OF MIGRATORY OR NON- MIGRATORY LIVING RESOURCES							
10. Concentrations of Marine Organisms							
Isotherms and isohalines exceeding tolerance range of important species	50	1000			0.5	0.5	7
Surface roughness (seaweed boundaries)	50	100					30

Laser Depth Sounding for  
Cartography - Resources Management

Applies to  
Fig. 24

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>LOCATION, ACCESSIBILITY, QUALITY, AND DEGREE OF EXPLOITATION OF MINERAL DEPOSITS</u>				
1. Mineral Deposits Water depth	300		5	30-60
<u>IDENTIFICATION OF POTENTIAL ENERGY SOURCES</u>				
△ 2. Tidal and Surf Action ▲ Nearshore bottom topography	200		5	INT (60)
<u>EXISTING AND POTENTIAL FRESH WATER SOURCES</u>				
7. Standing Water Reserves Water depth in lakes, reservoirs	200		1	7
<u>ASSESSMENT AND MANAGEMENT OF MIGRATORY OR NONMIGRATORY LIVING RESOURCES</u>				

## Visible and Near IR Spectrometry/Imaging for

Applies to  
Fig. 25

## Cartography - Physical Conditions

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>NAVIGATIONAL AND FISHING HAZARDS</b>						
1. Hazardous Currents ▲ Delineation of current boundaries (color contrasts)	.4-.7	.03	1000	50	.1-1.0	5
2. Biological Hazards ▲ Characteristic coloration of phytoplankton blooms and seaweed growth	.4-1.2	.05	100	50	.1-1.0	7
3. Shoal Water Water depth (spectral shift, turbidity, wave refractive patterns)	.4-.7	.02	100	50	.1-1.0	30 (& Int.-after storms)
4. Sea Ice Ice color (age)	.4-.7	.05	1000	50	.1-1.0	7
Sea ice boundaries	.4-.7	Bd	1000	50	1-10	7*
Bergs & floes	"	"	25	50	"	1
5. Icing Conditions ▲ Cloud formations	"	"	10 <sup>4</sup>	50	"	1
Sea state (glitter analysis)	.4-.7	"	NA	Glitter Pattern	1-10	1
6. High Winds and/or Heavy Seas Sea state (glitter analysis)	"	"	NA	Glitter Pattern	1-10	1
7. Obstacles to Trawling Depth & bottom type	"	"	100	50	"	Int (90)
<b>ENGINEERING INFORMATION</b>						
8. Bottom Character Bottom topography	.4-.7	.01	100	10	.1-1.0	Int (60)
Bottom composition (spectral analysis)	.4-.7	.05	100	10	.1-1.0	" (60)
9. Current Regime & Circulation Patterns Turbidity patterns	.4-.7	.03	100	10	.1-1.0	" (14)
Surface manifestations of internal waves (e.g., slicks)	.4-1.2	.05	300	10	.1-1.0	" (14)
Current patterns (color contrasts)	.4-.7	.03	100	10	.1-1.0	" (14)
* Daily coverage of the advance of ice into ports and important shipping lanes is needed. Weekly coverage is sufficient in permanent & semi-permanent pack ice regions.						
Bd - Broadband						

IR Radiometry/Imaging for  
Cartography - Physical Conditions

Applies to  
Fig. 25

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>NAVIGATIONAL AND FISHING HAZARDS</u>				
△ 1. Hazardous Currents				
▲ Delineation of current boundaries (thermal contrasts)	1000	50	1.0	5
3. Shoal Water				
Thermal contrasts indicative of shoals	100	50	1.0	30 (& int)
4. Sea Ice				
Melting/forming potential (thermal contrast)	1000	50	1.0	5
Sea ice boundaries	1000	50	1.0	7*
Bergs & floes	25	50	1.0	1
5. Icing Conditions				
▲ Cloud formations	10 <sup>4</sup>	50	NA	1
<u>ENGINEERING INFORMATION</u>				
9. Current Regime & Circulation Patterns				
Current patterns (thermal contrast)	100	10	1.0	Int (14)
Internal waves	300	10	0.5	" (14)

\* See Footnote, Page 4-15

Radar Scatterometry/Imaging for  
Cartograph - Physical Conditions

Applies to  
Fig. 25

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>NAVIGATIONAL AND FISHING HAZARDS</u>				
3. Shoal Water				
Surface roughness	100	50		30 (& Int)
Wave refractive patterns	100	50		30 (& Int)
4. Sea Ice				
Sea ice boundaries and gross topography	1000	50		7*
Bergs & floes	25	50		1
5. Icing Conditions				
Cloud formations	104	50		1
Sea state	N.A.	50	NBN (3-12)	1
6. High Winds and/or Heavy Seas				
Sea state	N.A.	50	NBN (3-12)	1
Wave directional spectrum	N.A.	50	10°	1
Wind fetch	N.A.	50	NBN (3-12)	1
<u>ENGINEERING INFORMATION</u>				
9. Current Regime & Circulation Patterns				
Surface manifestations of internal waves (e.g., slicks)	300	10	NBN (0-2)	Int (14)

\* See Footnote, Page 4-15

Precision Ranging for  
Cartography - Physical Conditions

Applies to  
Fig. 25

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>NAVIGATIONAL AND FISHING HAZARDS</u>					
1. Hazardous Currents					
▲ Surface slope (current vector)	300	10	$10^3$	10	5
3. Shoal Water					
Wave refractive patterns	25	.002	5	25	30
4. Sea Ice					
Ice thickness	50	1	$10^3$	10	7
5. Icing Conditions					
Wave profiling	25	.002	5	100	1
6. High Winds and/or Heavy Seas					
Wave profiling	25	.002	5	100	1
<u>ENGINEERING INFORMATION</u>					

Microwave Radiometry for  
Cartography - Physical Conditions

Applies to  
Fig. 25

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>NAVIGATIONAL AND FISHING HAZARDS</b>							
1. Hazardous Currents							
▲ Delineation of current boundaries (thermal and salinity contrasts)	50	1000			0.5	0.5	5
4. Sea Ice							
▲ Salinity correlations	50	1000				0.5	7
Ice thickness	50	1000					7
5. Icing Conditions							
Atmospheric thermal and humidity profile	50	N.A.			10%		1
Sea state	50	N.A.		NBN(3-12)			1
6. High Winds and/or Heavy Seas							
Sea state	50	N.A.		NBN(3-12)			1
Wind Fetch	50	N.A.		NBN(0-12)			1
<b>ENGINEERING INFORMATION</b>							
9. Current Regime & Circulation Pattern							
Current patterns (thermal and salinity contrasts)	10	100			0.5	0.5	Int(14)

Laser Depth Sounding for  
Cartography - Practical Conditions

Applies to  
Fig. 25

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>NAVIGATIONAL AND FISHING HAZARDS</u>				
3. Shoal Water Bottom topography	100		3	30 (6Int)
7. Obstacles To Trawling General bottom topography	300		3	Int (90)
<u>ENGINEERING INFORMATION</u>				
8. Bottom Character Water Depth	100		2	Int (60)

Visible and Near IR Spectrometry/Imaging for  
Cartography - Physical Conditions

Applies to  
Fig. 26

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>GEOLOGICAL PROCESSES</b>						
1. Coral Reefs						
Reef boundaries and depth	.4-.7	.02	100	50	.1-1.0	1/2 year
2. Erosion-Deposition						
Shoreline morphology	.4-.7	Bd	100	50	1-10	30 (& INT)
Bottom topographical changes	.4-.7	.01	1000	50	.1-1.0	30 (& INT)
Turbidity patterns	.4-.7	.1	100	50	.1-1.0	1
Δ 3. Eustatic Sea Level Changes						
▲ Terrestrial and ocean ice extent	.4-.7	Bd	1000	50	1-10	INT(1/2 Year)
Insolation/albedo	.4-.7	Bd	NA	50	1-10	INT(1/2 Year)
Atmospheric transparency (pollution)	.4-.7	Bd	N.A.	50	.1-1.0	INT(1/2 Year)
Δ 4. Volcanic Activity						
▲ Visible indications (smoke, steam, large ash deposits)	.4-.7	Bd	1000	50	1-10	INT (7)
5. Glaciation						
▲ Glacial extent and location	.4-.7	Bd	100	50	1-10	30
6. Pack Ice Dynamics						
Pack ice boundaries	.4-.7	Bd	1000	100	1-10	7-14
Ice color (age, thickness)	.4-.7	.05	1000	50	.1-1.0	7-14
Insolation/albedo	.4-.7	Bd	1000	50	1-10	INT (14)
Ice structure (leads, ridges. etc.)	.4-.7	Bd	100	50	1-10	7-14
<b>WEATHER CONDITIONS</b>						
7. Patterns of Weather						
Sea state	.4-.7	Bd	NA	glitter pattern	1-10	1
Cloud patterns and movements	.4-.7	Bd	10 <sup>4</sup>	50	1-10	1
Insolation/albedo	.4-.7	Bd	N.A.	50	1-10	1
Cloud height (oblique view, shadow displacement)	.4-.7	Bd	NA	glitter pattern	1-10	1

IR Radiometry/Imaging for  
Cartography - Physical Conditions

Applies to  
Fig. 26

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<b>GEOLOGICAL PROCESSES</b>				
2. Erosion-Deposition Shoreline morphology	100	50		30 (& INT)
△ 3. Eustatic Sea Level Changes				
▲ Polar ice pack extent	1000	100		INT (1/2 Year)
Insolation/albedo	N.A.	50		INT (1/2 Year)
Atmospheric emissivity properties (pollution)	N.A.	50		INT (1/2 Year)
△ 4. Volcanic Activity				
▲ Thermal characteristics	50	50	1.0	INT (7)
△ 5. Glaciation				
▲ Glacial extent and location	100	50		30
6. Pack Ice Dynamics				
Pack ice boundaries	1000	100		7-14
Insolation/albedo	1000	50		7-14
Surface temperature	1000	50	0.5	7-14
Ice structure (leads, ridges, etc.)	100	50		7-14
<b>WEATHER CONDITIONS</b>				
7. Patterns of weather				
Surface temperature	10 <sup>4</sup>	50		1
Cloud patterns and movements	10 <sup>4</sup>	50		1
Insolation/albedo	NA	50		1

Radar Scatterometry/Imaging for  
Cartography - Physical Conditions

Applies to  
Fig. 26

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>GEOLOGICAL PROCESSES</u>				
2. Erosion-Deposition Shoreline morphology	100	50		30 (& INT)
△ 3. Eustatic Sea Level Changes ▲ Polar ice pack extent	1000	100		INT (1/2 Year)
△ 5. Glaciation ▲ Glacial extent and location	100	50		30
6. Pack Ice Dynamics Pack ice boundaries	1000	100		7-14
Ice structure (leads, ridges, etc.)	100	50		7-14
<u>WEATHER CONDITIONS</u>				
7. Patterns of Weather				
Sea state	N.A.	50	NBN(3-12)	1
Cloud cover	10 <sup>4</sup>	50		1
Precipitation (cloud density)	10 <sup>4</sup>	50		1

Precision Ranging for  
Cartography - Physical Conditions

Applies to  
Fig. 26

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>GEOLOGICAL PROCESSES</u>					
△ 3. Eustatic Sea Level Changes					
▲ Global mean sea level	N.A.	100	$10^3$	10	INT (1 Year)
△ 4. Volcanic Activity					
▲ Volcanic island profiles	100	1	10	50	INT (1 Year)
<u>WEATHER CONDITIONS</u>					
7. Patterns of Weather					
Sea surface depressions and elevations indicative of atmospheric highs and lows	100	1	$10^3$	$10^4$	1
Cloud height	50	2	$10^3$	$10^4$	1

Microwave Radiometry for  
Cartography - Physical Conditions

Applies to  
Fig. 26

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>GEOLOGICAL PROCESSES</u>							
3. Eustatic Sea Level Changes							
Insolation/albedo	50	N.A.					INT (1/2 Year)
Atmospheric emissivity properties (pollution)	50	N.A.					INT (1/2 Year)
6. PACK ICE DYNAMICS							
Pack ice boundaries and thickness	100	1000					7-14
Atmospheric thermal and humidity profiles	50	N.A.					7-14
Heat flux	50	N.A.					7-14
Surface temperature	50	1000					7-14
<u>WEATHER CONDITIONS</u>							
7. Patterns of Weather							
Cloud cover	50	10 <sup>4</sup>					1
Temperature and humidity profiles	50	N.A.					1
Heat flux	50-100	N.A.	0.2				1
Sea state	300	10 <sup>4</sup>		NBN (3-12)			1
Precipitation	50	10 <sup>4</sup>					1
Surface temperature	50	10 <sup>4</sup>			0.5		1
Insolation/albedo	50	N.A.					1

**Applies to  
Fig. 26**

4-26

Visible and Near IR Spectrometry/Imaging for  
Cartography, Hydrology, and Geology - Coastal Structures

Applies to  
Fig. 27

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
EVALUATING ALTERATIONS TO COASTAL PROCESSES BY CONTROLLING STRUCTURES (GROINS, JETTIES)						
Sea state and refractive patterns (glitter analysis)	.4-.7	Bd	25	50	1-10	INT (14)
Bottom color (as indicative of composition)	.4-.7	.05	100	10	.1-1.0	30
Turbidity	.4-.7	.1	100	10	.1-1.0	INT (14)
Beach width and spectral reflectance (as indicative of composition)	.4-.7	.05	10-25	10	.1-1.0	INT (14)
Water color (as indicative of pollution)	.4-1.2	.05	100	10	.01-.1	1
Dye patterns (for tracing pollution phenomena or sediment transportation)	.4-.7	.01	50	10	.01-.1	1/24
Changes in abundance or location of benthic algae	.6-1.2	.02	50-100	10	.1-1	30
Disposition of phytoplankton blooms	.4-1.2	.05	100	10	.1-1.0	INT (14)
Terrestrial vegetation	.4-1.2	.1	10	10	1-10	INT (60)
Nearshore bottom topography	.4-.7	.01	100	10	.1-1	7-14

IR Radiometry/Imaging for  
Cartography, Hydrology, and Geology - Coastal Structures

Applies to  
Fig. 27

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>EVALUATING ALTERATIONS TO COASTAL PROCESSES BY CONTROLLING STRUCTURES (GROINS, JETTIES)</u>				
Thermal pollution patterns	100	10	±0.5	5
Isotherm mapping of current patterns	300	50	±0.5	INT (30)
Kelp bed extent (water temperature)	100	10	±0.5	30
Beach width	10-25	10	--	INT (14)

Radar Scatterometry/Imaging for  
Cartography, Hydrology, and Geology - Coastal Structures

Applies to  
Fig. 27

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>EVALUATING ALTERATIONS TO COASTAL PROCESSES BY CONTROLLING STRUCTURES (GROINS, JETTIES)</u>  Sea state and refractive patterns	10-20	50	NBN(3-12)	INT (14)

Precision Ranging for  
Cartography, Hydrology, and Geology - Coastal Structures

Applies to  
Fig. 27

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<p>EVALUATING ALTERATIONS TO COASTAL PROCESSES BY CONTROLLING STRUCTURES (GROINS, JETTIES)</p> <p>Wave profiling</p>		5-10 feet	1-2	±50	INT (14)

**Microwave Radiometry for  
Cartography, Hydrology, and Geology - Coastal Structures**

**Applies to  
Fig. 27**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<u>EVALUATING ALTERATIONS TO COASTAL PROCESSES BY CONTROLLING STRUCTURES (GROINS, JETTIES)</u>							
Sea state	50	NA		NBN(3-12)			INT (14)
Isothermal and isohaline mapping of current patterns	50	300			0.5	0.5	INT (30)

Laser Depth Sounding for  
Cartography, Hydrology, and Geology - Coastal Structures

Applies to  
Fig. 27

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>EVALUATING ALTERATIONS TO COASTAL PROCESSES BY CONTROLLING STRUCTURES (GROINS, JETTIES)</u>  Nearshore bottom topography	20	N.A.	<u>+3</u>	7

Visible and Near IR Spectrometry/Imaging for  
Cartography, Hydrology, and Geology - Coastal Structures

Applies to  
Fig. 28

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>SURVIVAL OF MAN MADE COASTAL STRUCTURES</b>						
1. Earthquake Forces and Motions						
▲ Structural geology (location of fault systems)	.4-.7	Bd	100	50	1-10	INT (1 Year)
2. High Wind Forces						
Sea state (glitter analysis and presence of whitecaps)	.4-.7	Bd	NA	glitter pattern	1-10	INT (7)
Cloud patterns	.4-.7	Bd	1000	50	1-10	INT (7)
Smoke plumes	.4-.7	Bd	100	50	1-10	INT (7)
3. Tsunami Damage Potential						
Nearshore bottom topography and coastline configuration	.4-.7	.01	500	50	.1-1.0	INT (1 Year)
Tsunami wave trains (glitter)	.4-.7	Bd	50	300	1-10	INT (1/24)
4. High Sea States						
Sea state (glitter analysis)	.4-.7	Bd	NA	glitter pattern	1-10	INT (7)
Water Depth	.4-.7	.02	100	50	.1-1.0	INT
5. Effects of Normal Sea and Swell Waves						
Sea state nearshore	.4-.7	Bd	NA	glitter pattern	1-10	INT (7)
Wave refraction	.4-.7	Bd	50	50	1-10	INT (7)
Surf zone width	.4-.7	Bd	10	50	1-10	INT (7)
6. Rates of Sediment Erosion and Deposition						
Nearshore bottom topography and coastline configuration	.4-.7	.01	500	50	.1-1.0	INT (7)
Turbidity	.4-.7	.05	100	50	.1-1.0	INT (7)
Bottom composition	.4-.7	.05	100	50	.1-1.0	INT (14)
Wave refraction	.4-.7	Bd	50	50	1-10	INT (7)
7. Storm Surges, Tides, and Nearshore Currents						
Turbidity	.4-.7	.05	100	50	.1-1.0	INT (7)
Coastline configuration	.4-.7	Bd	100	50	1-10	INT (30)
▲ Bottom topography	.4-.7	.02	100	50	.1-1.0	INT (30)
8. Meteorological Effects						
▲ Wind driven sea state (glitter analysis)	.4-.7	Bd	200	50	1-10	INT (7)
Smoke plumes	.4-.7	Bd	100	50	1-10	INT (7)
9. Stresses Due to Formation of Sea Ice						
▲ Sea ice motions and extent	.4-.7	Bd	10	50	1-10	INT (1)

IR Radiometry/Imaging for  
Cartography, Hydrology, and Geology - Coastal Structures

Applies to  
Fig. 28

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K	Observation Frequency Days
<u>SURVIVAL OF MAN MADE COASTAL STRUCTURES</u>				
1. Earthquake Forces and Motions				
▲ Structural geology (location of fault systems)	100	50	--	INT (1 Year)
2. High Wind Forces				
Cloud patterns	1000	50	--	INT (7)
3. Tsunami Damage Potential				
Coastline configuration	500	50	--	INT (1 Year)
6. Rates of Sediment Erosion and Deposition				
Coastline configuration	500	50	--	INT (7)
7. Storm Surges, Tides and Nearshore Currents				
Coastline configuration	500	50	--	INT (30)
Δ 9. Stresses Due to Formation of Sea Ice				
▲ Sea ice motions and extent	10	50	1.0	INT

Radar Scatterometry/Imaging for  
Cartography, Hydrology, and Geology - Coastal Structures

Applies to  
Fig. 28

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>SURVIVAL OF MAN MADE COASTAL STRUCTURES</u>				
1. Earthquake Forces and Motions				
▲ Structural geology (location of fault systems)	100	50	--	INT. (1 Year)
2. High Wind Forces				
Sea state	NA	50	NBN (3-12)	INT. (7)
Cloud patterns	1000	50	--	INT. (7)
3. Tsunami Damage Potential				
Coastline configuration	100	50	--	INT. (1 Year)
Tsunami wave trains	10	300	--	INT. (1/24)
4. High Sea States				
Sea state	NA	50	NBN (3-12)	INT. (7)
5. Effects of Normal Sea and Swell Waves				
Sea state nearshore	NA	50	NBN (3-12)	INT. (7)
Wave refraction	50	50	--	INT. (7)
6. Rates of Sediment Erosion and Deposition				
Coastline configuration	100	50	--	INT. (7)
Wave refraction	50	50	--	INT. (7)
7. Storm Surges, Tides, and Nearshore Currents				
Coastline configuration	100	50	--	INT. (30)
Δ8. Meteorological Effects				
▲ Wind driven sea state	NA	50	NBN	INT. (7)
Δ9. Stresses Due to Formation of Sea Ice				
▲ Sea ice motions and extent	10	50	--	INT.

Precision Ranging for

Cartography, Hydrology, and Geology - Coastal Structures

Applies to  
Fig. 28

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>SURVIVAL OF MAN MADE COASTAL STRUCTURES</u>					
1. Earthquake Forces and Motions					
▲ Altimetric indications of landshifts	100	1	10	50	INT. (1 Year)
2. High Wind Forces					
Sea state (wave profile)	10	5-10 feet	1-2	50	INT. (7)
4. High Sea States					
Sea state (wave profile)	10	5-10 ft.	1-2	50	INT. (7)
5. Effects of Normal Sea and Swell Waves					
Sea state (wave profile)	10	5-10 ft.	1-2	50	INT. (7)
Wave refraction	10	.004	10	25	INT. (7)
6. Rates of Sediment Erosion & Deposition					
Wave refraction	10	.004	10	25	INT. (7)
7. Storm Surges, Tides, and Nearshore Currents					
Storm surge sea levels	100	1	10 <sup>3</sup>	5	INT. (1 Hour)
△ 9. Stresses Due to Formation of Sea Ice					
▲ Sea ice surface contours and thickness	10	1	10 <sup>3</sup>	10	INT. (7)

**Microwave Radiometry for**  
Cartography, Hydrology, and Geology - Coastal Structures

**Applies to**  
**Fig. 28**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b>SURVIVAL OF MAN MADE COASTAL STRUCTURES</b>							
2. High Wind Forces							
Sea state	50	NA		NBN(3-12)			INT.(7)
Cloud patterns	50	1000					INT.(7)
4. High Sea States							
Sea state	50	NA		NBN(3-12)			INT.(7)
5. Effects of Normal Sea and Swell Waves							
Sea state nearshore	50	NA		NBN(3-12)			INT.(7)
8. Meteorological Effects							
Humidity/temperature profiles	50	NA		--			INT.(7)
9. Stresses Due to Formation of Sea Ice							
Sea ice thickness and extent	50	1000		--			INT.(7)

Laser Depth Sounding for  
Cartography, Hydrology, and Geology - Coastal Structures

Applies to  
Fig. 28

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>SURVIVAL OF MAN MADE COASTAL STRUCTURES</u>				
3. Tsunami Damage Potential Nearshore bottom topography	300		3	INT. (1 Year)
4. High Sea States Nearshore bottom topography	300		3	INT.
6. Rates of Sediment Erosion and Deposition Nearshore bottom topography	300		1	INT. (7)
7. Storm Surges, Tides, and Nearshore Currents ▲ Bottom topography	300		3	INT. (30)

Visible and Near IR Spectrometry/Imaging for  
Cartography-Coastal Damage Survey

Applies to  
Fig. 29

Applications	Spectral Range $\mu$	Spectral Bandwidth $\mu$	Ground Resolution Feet	F.O.V. Miles	Sensitivity $w/m^2/ST/\mu$	Observation Frequency Days
<b>NATURAL HAZARDS</b>						
1. Fires						
Extent of burned areas	.4-.7	Bd	1000	50	1-10	INT (1)
Smoke plumes	.4-.7	Bd	1000	50	1-10	INC (1)
2. Coastal Flooding						
Flooding extent and duration	.4-.7	Bd	100	50	1-10	INT (1)
3. Tropical Storms						
High resolution visual survey of damage	.4-.7	Bd	10	10	1-10	INT
4. Earthquakes						
Gross topographic changes	.4-.7	Bd	100	50	1-10	INT
6. Tsunamis and Storms						
Areal extent of flooding	.4-.7	Bd	100	50	1-10	INT (1)
Coastline alterations	.4-.7	Bd	100	50	1-10	INT
7. Sea Life Depletion						
Coral reef tonal contrasts	.4-.7	.02	100	50	.1-1.0	30 (14)
Seaweed extent	.6-1.2	.02	50-100	10	.1-1.0	30 (30)
8. Red Tides, Anoxic Conditions						
Survey of extent and effects such as fish kills	.4-1.2	.05	100	50	.01-.1	INT (1)
9. Damage by Terrestrial Organisms						
Coastal ground cover depletion	.4-.7	Bd	100	50	1-10	14
Insect crop damage	.4-1.2	.02	100	50	.1-1.0	14
<b>DAMAGE DUE TO ARTIFICIAL HAZARDS</b>						
10. Oil Spills						
Deposits along coastlines	.4-.7	Bd	10	50	1-10	INC (1)
12. Sewage Contamination						
Color contrasts	.4-1.2	.05	100	10	.01-.1	INT (30)
Alterations in coastal sea life (kelp, coral, sea grass)	.6-1.2	.02	100	50	.1-1	30
13. Dredging Activities						
Water depth	.4-.7	.01	100	50	.1-1	INT (30)
Turbidity	.4-.7	.1	100	50	.1-1	INT (14)
Alterations to sea life and coastline	.6-1.2	.02	100	50	.1-1	INT (30)

# IR Radiometry/Imaging for

Cartography - Coastal Damage Survey

Applies to  
Fig. 29

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy °K <sub>i</sub>	Observation Frequency Days
<u>NATURAL HAZARDS</u>				
1. Fires Thermal patterns indicating areas of active burning	100	50		INT (1)
2. Coastal Flooding Flooding extent and duration	100	50		INT (1)
△ 5. Volcanic Activity ▲ Extent of thermal effects	100	50	10	INT (1)
6. Tsunamis and Storm Surges Areal extent of flooding Coastline alterations	100 100	50 50		INT (1) INT
7. Sea Life Depletion ▲ Correlative surface thermal properties	100	50	0.5	INT (30)
8. Red Tides, Anoxic Conditions ▲ Correlative surface thermal properties	100	50	0.5	INT (7)
<u>DAMAGE DUE TO ARTIFICIAL HAZARDS</u>				
13. Dredging Activities Changes in coastline configuration	100	50		INT (30)
14. Thermal Pollution Distribution of isotherms in vicinity of thermal source	50	50	0.2	INT (7)

Radar Scatterometry/Imaging for  
Cartography - Coastal Damage Survey

Applies to  
Fig. 29

Applications	Ground Resolution Feet	F.O.V. Miles	Accuracy	Observation Frequency Days
<u>NATURAL HAZARDS</u>				
2. Coastal Flooding Flooding extent and duration	100	50		INT (1)
4. Earthquakes Gross topographic changes	100	50		INT
6. Tsunamis and Storm Surges Areal extent of flooding	100	50		INT (1)
Coastline alterations	100	50		INT
<u>DAMAGE DUE TO ARTIFICIAL HAZARDS</u>				
13. Dredging Activities Changes in coastline configuration	100	50		INT (30)

Precision Ranging for  
Cartography - Coastal Damage Survey

Applies to  
Fig. 29

Applications	Field of View Miles	Sample Spacing Miles	Footprint Diameter Feet	Accuracy cm	Observation Frequency Days
<u>NATURAL HAZARDS</u>					
2. Coastal Flooding Water level	50	1	10	25	INT (1)
4. Earthquakes Shifts in land mass	100	1	10	50	INT
6. Tsunamis and Storm Surges Surge water height and seaward extent	50	1	10	50	INT (10 Minutes)
<u>DAMAGE DUE TO ARTIFICIAL HAZARDS</u>					

**Microwave Radiometry for  
Cartography - Coastal Damage Survey**

**Applies to  
Fig. 29**

Applications	Field of View Miles	Ground Resolution Feet	Accuracy Heat Flux cal/cm <sup>2</sup> /min	Accuracy Sea State	Accuracy Temp °K	Accuracy Salinity o/oo	Observation Frequency Days
<b><u>NATURAL HAZARDS</u></b>							
2. Coastal Flooding Saline incursion	50	100				1.0	INT (1)
6. Tsunamis and Storm Surges Saline incursion	50	100				1.0	INT (1)
7. Sea Life Depletion Correlative surface thermal and salinity properties	50	100			0.5	0.5	INT (30)
8. Red Tides. Anoxic Conditions Correlative surface thermal and salinity properties	50	100			0.5	0.5	INT (7)
<b><u>DAMAGE DUE TO ARTIFICIAL HAZARDS</u></b>							

Laser Depth Sounding for  
Cartography - Coastal Damage Survey

Applies to  
Fig. 29

Applications	Sample Spacing Feet	Ground Resolution Feet	Accuracy Feet	Observation Frequency Days
<u>NATURAL HAZARDS</u>				
2. Coastal Flooding Flood depths	100		1	INT (1)
7. Sea Life Depletion Water depth changes (reef destruction by waves)	50		3	1/2 Year
<u>DAMAGE DUE TO ARTIFICIAL HAZARDS</u>				
13. Dredging Activities Water depth	100		3	INT (30)

Table A-1. Tabulation of Sensor Requirements from Previous and On-going Space Programs

PROGRAM	LAUNCH DATE	ORBIT	SENSORS	SPECTRAL CHANNELS	RESOLUTION
TIROS M	23 January 1970	h = 1460 KM Orbit = Polar, Sun-Synchronous $\Omega$ = 3:00 p. m. Local Time	Advanced Vidicon Camera System (AVCS) - Redundant Automatic Picture Transmission System (APT) - Redundant Flat Plate Radiometer Solar Proton Monitor	(0.3 - 30 $\mu$ ) (0.27 - 60 MEV) (100 - 750 KEV) (12.5 - 32 MEV)	< 1 NM ~ 2 NM 2 $\pi$ ster - - - - - -
ITOS A	10 December 1970	Same As Above	Same As Above	Same As Above	Same As Above
ITOS B	August 1971	Same As Above	Same As Above	Same As Above	Same As Above
ITOS C - PRIME	December 1971	h = 1460 KM Orbit = Polar, Sun-Synchronous $\Omega$ = 9:00 a.m. or 3:00 p.m. Local Time	Vertical Temperature Profile Radiometer (VTPR) Scanning Radiometer (SR) - Redundant Infrared Interferometer Spectrometer - D (IRIS-D) Very High Resolution Radiometer (VHRR)	8 Bands 11-19 $\mu$ Region 2 Bands: .52 - .73 $\mu$ , 10.5 - 12.5 $\mu$ 6.25 - 50 $\mu$ range 2 Bands: .5 - .7 $\mu$ , 10-2.5 $\mu$	0.4 Deg.
ITOS D	March 1972	h = 1460 KM Orbit = Polar, Sun-Synchronous $\Omega$ = 9:00 a. m. or 3:00 p. m. , Local Time	Very High Resolution Radiometer (VHRR) - Redundant Vertical Temperature Profile Radiometer (VTPR) - Redundant Scanning Radiometer (SR) - Redundant Flat Plate Radiometer Solar Proton Monitor	2 Bands: .5 - .7 $\mu$ , 10-2.5 $\mu$ 8 Bands: 11-19 $\mu$ Region 2 Bands: .52 - .73 $\mu$ , 10.5 - 2.5 $\mu$ .3 - 30 $\mu$ .27-60, 12.5-32, 100-750 MEV	2 - ster
ITOS E	October 1972	Same As Above	Same As Above		
ITOS F	June 1973	Same As Above	Same As Above		
ITOS G	March 1974	Same As Above	Same As Above		
TIROS N	1975	h = 1700 KM Orbit = Polar, Sun-Synchronous (Adjustable) $\Omega$ = Flexible	Advanced Very High Resolution Radiometer (AVHRR) Improved Atmospheric Sounder Data Collection System	VIS & IR, 2 or More Bands 21 Bands: 3.8 to 15 $\mu$	1/2-2 NM

Table A-1. Tabulation of Sensor Requirements from Previous and On-going Space Programs (Continued)

PROGRAM	LAUNCH DATE	ORBIT	SENSORS	SPECTRAL CHANNELS	RESOLUTION
<b>TIROS O</b>					
SMS A	July 1972	h = 35,500 KM Orbit = Equatorial Geostationary	Visible/Infrared Spin-Scan Radiometer (VISSR) Data Collection System Data Relay System Space Environment Monitoring System	.55-.70 $\mu$ , 10.5-12.6 $\mu$	0.5-4 NM
SMS B	January 1973	Same As Above	Same As Above		
SMS C (GEOS A)	January 1974	Same As Above	Same As Above		
NOAUS D	April 9, 1970	h = 1100 KM Orbit = Polar, Sun-Synchronous Q = 12:00 Noon	Filter Wedge Spectrometer (FWS) Selective Chopper Radiometer (SCR) Backscatter Ultraviolet Experiment (BUV) Monitor of Ultraviolet Solar Energy (MUSE) Image Dissector Camera System (IDCS) Infrared Interferometer Spectrometer (IRIS-B) Interrogation, Recording and Location System (IRLS) Satellite Infrared Spectrometer (SIRS-B) Temperature/Humidity Infrared Radiometer (THIR)	1.2-2.4, 3.2-6.4 $\mu$ 14.5-15 $\mu$ , 3 Channels 14 Bands: .25-.34 $\mu$ 5 Channels .115-.3 $\mu$ Visible 8-40 $\mu$ 11.1-36 $\mu$ 6.5-7 $\mu$ , 10.5-12 $\mu$	800 Lines Over 14-00 NM       6.5 NM
NOAUS E	August 1972	h = 1100 KM Orbit = Polar Sun-Synchronous Q = 12:00 Noon	Selective Chopper Radiometer (SCR) Infrared Temperature Profile Radiometer (ITPR) Microwave Spectrometer (MWS) Electrically Scanning Microwave Radiometer (ESMR) Temperature/Humidity Infrared Radiometer (THIR) Surface Composition Mapping Radiometer (SCMR) Real-Time Data Relay (RDR)	8-200 $\mu$ , 13 Bands 6 Bands: 11-40 $\mu$ .465-1.35 cm, 5 Bands 1.55 cm 6.5-7 $\mu$ , 10.5-12 $\mu$ 8.4-9.4, 10.2-11.4 $\mu$	26 NM      0.6 KM

Table A-1. Tabulation of Sensor Requirements from Previous and On-going Space Programs (Continued)

PROGRAM	LAUNCH DATE	ORBIT	SENSORS	SPECTRAL CHANNELS	RESOLUTION
NIMBUS F	September 1973	h = 1100 KM Orbit = Polar, Sun-synchronous Ω = 12:00 Noon	Tropical Wind, Energy Conversion, and Reference Level Experiment (TWERLE)		
			High Resolution Infrared Sounder (HIRS)	16 Bands: 3.8-15 μ	
			Near-Infrared Multi-Detector Grating Spectrometer	44 Bands: 3.8-15.8 μ	
			Mapping Microwave Spectrometer	.465-1.35 cm	
			Temperature/Humidity Infrared Radiometer (THIR)	6.5-7, 10.5-12 μ	
			Limb Radiance Inversion Experiment	4 Channels 9.4-40 μ	
			Earth Radiation Budget (ERB)	0.2-40 μ	
			Pressure Modulated Carbon Dioxide Radiometer	2 Bands: 15 μ Region	
			Electrically Scanning Microwave Radiometer (ESMR)	0.8 cm	
			Solar Cosmic Ray and Trapped Particle Experiment	0.2-280 MEV	
ERTS A	March 1972	h = 920 KM Orbit = Polar, Sun-synchronous Ω = 9:30 a.m., Local Time	Electrostatic Probe Studies	1-20 AMV	
			Positive Ion Composition Experiment		
			Return Beam Vidicon Camera (RBV)	.48-.58, .58-.68, .69-.83 μ	200'
			Multispectral Scanner (MSS) Data Collection System	4 Bands: .5-1.1 μ +10.4-12.6 μ (ERTS B)	150-300'
ERTS B	March 1973	Same As Above	Same As Above		
GEODETIC SATELLITE	Mid 1972	h = 3700 KM Orbit = 55° Inclined	Geocentric Positioning Experiment		
SKYLAB	November 1962	h = 435 KM Orbit = 50° Inclined	Multispectral Photography Facility (S-190)	6 Bands: .5-.9 μ	100'
			Infrared Spectrometer (S-191)	.4-2.4, 6.2-15.5 μ	
			Ten-Band Multispectral Scanner (S-192)	10 Bands: .4-2.35, 10.2-12.5 μ	130-230'
			Microwave Radiometer/Scatterometer (S-193a) Microwave Altimeter (S-193b) Microwave Radiometer (S-194)	13.4 GHz 9.4 GHz 1.4 GHz	

**APPENDIX B**

**SYNOPSIS OF  
USER SURVEY RESULTS**

A significant part of the study was a review of our established needs and data requirements for the coastal zone, prior to finalizing the performance goals for the sensor study. This review was performed by a selected group of professionals active in the oceanographic community. Table B-1 which is a list of the selected individuals, describes the special interests of each.

The review package consisted of 1) the fold-out volume of logic trains (matrices) linking national priorities to space observables (an edited version of these matrices appears in ~~the text~~ <sup>Sections 3 and 4</sup> of this report ~~on pages~~ through and 2) a companion volume listing resolution, sensitivity, and observational frequency requirements (sensor performance requirements) for each remote space observable in the matrices of the first volume. (Appendix A). Some of the "Associated Phenomena" of the first volume were deemed by us to be of minor importance to the corresponding "implied information needs". These were called out in the second volume and the survey group was requested to examine these designations.

Responses were provided by the persons whose names appear in Table B-1. Many of the respondents' comments were of a general or philosophical nature. The essence of our discussions are presented below in informal telephone contact reports or in copies of letters returned by the survey participants. Some respondents, on the other hand - notably contacts 2 and 3 - took a hard look specifically at our sensor performance requirements (second volume). While a contact report as such is not included here for those participants, their quantitative recommendations were taken into consideration prior to final specification of mission performance characteristics. A contact report also does not exist for Dr. North (contact number 7), the reason being that he served as a consultant during the course of the study and therefore did not serve in a review capacity.

**TABLE B-1 : USER SURVEY RESPONSES**

<u>NAME OF CONTACT</u>	<u>AGENCY REPRESENTED</u>	<u>PRIORITY</u>	
		<u>Primary Contribution</u>	<u>Secondary Contribution</u>
1. William S. Davis	Federal Water Quality Administration	Pollution	Hazards
2. Mel Greenwood (for Harvey Bullis)	NMFS (National Marine Fisheries Service)	Fisheries	Pollution
3. G. Carper Tevinkel (instead of Capt. L. W. Swanson)	Coast and Geodetic Survey	Cartography	Hazards
4. Henry Yatko (instead of John W. Sherman)	NavOceano	General	
5. Taivo Laevastu	Fleet Numerical Weather Central (U.S. Navy)	Fisheries	Hazards
6. Robert Dow	Maine Department of Sea and Shore Fisheries	Fisheries	
7. Wheeler J. North	California Institute of Technology	Pollution	
8. Edward Ehlers (instead of Robert Walker)	California Department of Navigation and Ocean Development	Cartography	
L. H. Cloyd Ed Greenhood Robert Lewis	California Department of Fish and Game	Fisheries	
	California Department of Fish and Game	Fisheries	
	California Water Quality Board	Pollution	
9. Gordon Broadhead and Frank Alverson	Living Marine Resources, Inc.	Fisheries	Hazards
<u>responses also solicited from:</u>			
Richard Madruga	(fishing vessel captain)	Fisheries	
ADM. Leslie Gheres	(Manager of National Marine Terminal — an operator of 12 tuna vessels)	Fisheries	
Harold Cary	(Vice President of a seafood processing and marketing company [Westgate, California])	Fisheries	

Telephone conversation on November 13th with Bill Davis representing the Federal Water Quality Administration.

Bill Davis' comments were fairly general at first, he had some thoughts on optimal flight paths for such a satellite system. First of all he felt that it should be parallel to the coastline, in other words a capability should exist for observation of all the coastlines in the United States and he felt that the Great Lakes regions were the most important. We discussed the tradeoffs associated with observational frequency and spatial and spectral resolution and asked if he felt that a satellite system that was geared for daily observations but missed large sections of U.S. coastline would be preferred over a system that obtained weekly observations but examined the entire coast, and he seemed to prefer the latter situation. He argued for a system that would have a great deal of flexibility built into it. He felt that cloud cover was a very important consideration as far as the opportunity to give good observations is concerned, therefore he would want to have as many looks as possible at a certain area. Other flexibility factors that he was considering were the ability to change orbit during a mission and especially the ability to change data rates, also the ability to look at different areas in different times, in other words to address pollution situations as they arise. He felt that one of the major contributions of such a satellite system would be the advantages it would have for locating areas where you would want to place survey stations.

He suggested that we may have omitted a category of major importance in our discussion and in our matrices which has to do with patterns of use. As far as activities in coastal areas are concerned he is talking mainly about daily use patterns which are indicative of our involvement with our environment. An example of this would be occupation of transportation routes, i.e., the number of cars on the highways at various times of day. He mentioned ship traffic in the area of the Straits of Florida. During certain times of the day and during certain seasons these lanes are very clogged with shipping activities and the probability of a pollution event arising, say, from a collision, is very high. He suggested that if we could get down to 10 foot resolution level we can even obtain information on pleasure boat use patterns.

Telephone conversation Thursday am November 12th, 1970 with  
Henry Yanko of SPOC - Navoceano

Subject: Users Survey

The first comment was that he was overwhelmed with the size of the package and felt that we had certainly not left anything out. He was worried that we were going to possibly conclude that nothing could be done from space if we set such hard requirements on all of the individual phenomenon measurements. He commented that this problem has arisen before in every users survey and most of the users have felt that there was very little use for remote sensing because it could not meet each of the minute requirements. He wanted to stress that he hoped that our study would conclude that remote sensing is not necessarily competitive with other ground measurements performed by users, but rather that remote sensing would be complimentary to the ground-based measurements. He pointed out that many times the usefulness of remote sensing is of an indicative nature, in other words the remote measurement detect indications of phenomena or processes occurring even if they do not directly measure the phenomena. In addition, he hopes that we will stress where the spacecraft might have a unique contribution. He made the point that he thought that one of the major payoffs would be that for the users in question, satellite remote sensing would place phenomena in perspective, in other words it would show relation of point measurements over broad areas in time and it would enable the users to better judge where they should place point measurements.

He realized that the directive of our study was to do a top down analysis - to first determine what are the coastal needs and problems for the national concern and then to filter the study to determine how a satellite might best contribute to these problems. He knows that we are directed to go in that direction although he thinks that a better attack would be to first define all of those surface features that might be amenable to remote sensing and marry the indicative measurements to the problem as described by surface measurements. He laid out three steps with regards to his preferred attack: (1) determine which surface features amenable to remote sensing, (2) determine if they are indicative

of important phenomena, and (3) determine if they can be measured. He gave us one example regarding salinity. Salinity in the near future will not be a direct measurable from space but with regards to saline intrusion, salinity may have a strong correlation with the thermal measurement. Since temperature can be measured from space, an indication of saline intrusion may be detectable.

He brought up the point that the Geonautics study is near completion and that they have performed a user survey. They have asked the users for their spatial and spectral temporal requirements and have run into some of the same problems mentioned above: the requirements were so stiff that it was doubtful whether space remote sensing may be applicable to their problems. Nevertheless, he said that he would send us a copy of their results with regards to measurement requirements.

We asked him if he had any opinions with regards to orbit parameters. In particular, we asked if he thought that a global scheme is preferable over coverage of particular coastal areas of national concern, bearing in mind the spatial and temporal resolution tradeoffs involved. He mentioned that they have been battling with these problems for quite some time and that they had not really drawn conclusions. He suggested that perhaps two geosynchronous satellites would be the answer for national problems and that at times you may want to piggyback a nondedicated satellite for these purposes. His final conclusion was that nobody at this time really knows what is required to do the oceanographic job and he hopes that our study will answer some of these questions.

He felt that while two geosynchronous satellites might satisfy the national requirements appropriately, the international problem would best be met either by a polar satellite or one in an inclined orbit.

To conclude, he did not have any specific criticism of our individual specifications with regards to measurement requirements. Basically he felt that we had gone about it in a manner in which we were directed but would like to see a study that came in the middle rather than using a top down needs analysis. We pointed out that we felt the purpose of the study was to strongly relate the capabilities of remote sensing to national needs with the belief that the satellite programs dedicated to oceanography would

not get off the ground in the political climate of today unless it was related to the man on the street. This could only be done by beginning the study with the national needs and proceeding towards a satellite definition and the relevancy analysis that relates to these needs.

## Trip Report

Visit to: Dr. Taivo Laevastu

The trip was taken on November 13th by Lee Peterson and Gerald Johnson. In our initial telephone conversations with Dr. Laevastu he expressed serious doubts concerning satellite programs and therefore we felt it necessary to visit him personally in order to better explain our approach and the possible utility of satellites. This is a brief report of his comments during our visit.

First a few general comments about his philosophy. He has for a long time been involved in classical weather prediction. His position is with the U.S. Navy Fleet Numerical Weather Central in Monterey and he feels that his agency is doing an adequate job in this area already. Presently he receives world-wide reports on sea surface temperature, sea state, and atmospheric properties. He recognizes there are some inadequacies in their reporting of meteorological facts but he feels that a satellite probably has little to offer in filling those gaps. Although he is openly pessimistic about satellite applications he does not want to mislead us in the fact that he hopes that there will be continued study and that the programs will be funded so that we can better learn how satellites might be used. However, he is doubtful about the capabilities of spacecraft sensors for obtaining the needed information and feels that it may be as long as fifty years before the capability of sensors may come up to his needs.

With respect to his specific needs for data in regards to weather prediction he feels that he does not need better sea state information, or information on storm locations, storm surges, or tides. These conditions are already adequately modeled by his computer algorithms and modeling programs. His greatest need is for sea surface temperature, but he feels that if we cannot provide accuracies of  $0.1^{\circ}$  C, the data from satellites would probably only contaminate the data he now uses. He feels that the major role for satellites in the next decade would be in the data relay and data management area. In addition, he suggests that satellites would be very useful as navigational aids to ships at sea.

It was apparent that Dr. Laevastu's most basic concerns were in the area of priorities. Although he feels that satellite studies and the launching of experimental satellites is proper at this time, it should not be done without the support of the classical programs that have been in operation for many years. He has experienced what he considers to be serious cutbacks in his program because people feel that information he is seeking to obtain will be obtainable by satellite in "just a few years". He is very skeptical about these promises and in the meantime the development of his program into greater usefulness is limited. In addition, he feels that a report such as ours may mislead many people into feeling that satellites can do more than is actually true. We identify many possibilities for remote sensing from space but if we are not very careful in clarifying which of those are really feasible in the next ten years, people will tend to be overly-optimistic about remote sensing and, again, support of the classical efforts to obtain this information will be restricted. In all fairness to Dr. Laevastu, we must conclude this trip report by stating that these are his most honest concerns, he is by no means against the advancement of satellite systems and satellite technology but he would like to see it advance in a balanced manner whereby other priorities are also satisfied.

Dr. Laevastu was one of the more critical members of our user survey team. Accordingly, we felt it was very important to listen carefully to his comments so that we would be better able to defend our position in establishing the relevancy of ERTS-E and -F for oceanography.

RONALD W. GREEN, COMMISSIONER



STATE OF MAINE

DEPARTMENT OF SEA AND SHORE FISHERIES

STATE HOUSE

AUGUSTA, MAINE 04330

November 12, 1970

Mr. B. R. Loya  
ER TS E/F Project Manager  
Systems Group of TRW Inc.  
One Space Park  
Redondo Beach, Calif. 90278

Dear Mr. Loya:

Having received the second volume of measurement requirements for ER TS E/F, I have reviewed further the proposal. My only comments are the following:

Page 2-7, and Figure 14. Under the heading "Year Class - Specific Spawning Success" no mention has been made of sea temperature fluctuations associated with the spawning pattern in some species. For example, a drop in temperature followed by a rise is associated with the onset of sea scallop (Placopecten magellanicus) spawning.

Contrasting phenomena include long-term subcycles, as apparently have occurred in the Gulf of Maine since the middle of the 19th Century. Menhaden (Brevoortia tyrannus) was the principal commercially-exploited finfish resource in the Gulf of Maine until the early 1900's. The decline in abundance has been associated with the approximately 40-year temperature declining subcycle which terminated with the historic record low in 1917, as measured at Boothbay Harbor, Maine, by the U. S. Fish and Wildlife Service. Menhaden did not appear in abundance again until toward the end of the following 40-year subcycle of increasing temperature. This cycle terminated with a record high in 1953. Since that time, temperatures have declined consistently and so has the abundance of menhaden.

Page 2-13, and Figure 15. Ice cover frequently is a problem in shallow and in coastal waters. One factor has been observed in addition to the effects of low temperatures on some species -- the influence on water quality, creating a

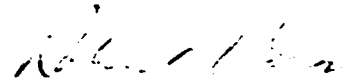
Mr. B. R. Loya

-2-

November 12, 1970

reduction in dissolved oxygen and an increase in mortality rate. This phenomenon appears to be, in part at least, a result of failure of surface to bottom mixing. With the imposition of ice between the air and water, the normal oxygenation process is eliminated or drastically reduced, even in an area of considerable tidal range.

Sincerely yours,



ROBERT L. DOW,  
Marine Research Director

RLD/jwu

RONALD W. GREEN, COMMISSIONER



STATE OF MAINE

**DEPARTMENT OF SEA AND SHORE FISHERIES**

STATE HOUSE

AUGUSTA, MAINE 04330

November 9, 1970

Mr. B. R. Loya  
ER TS E/F Project Manager  
Systems Group of TRW Inc.  
One Space Park  
Redondo Beach, Calif. 90278

Dear Mr. Loya:

I frankly admit that I do not understand the implications of the proposed "Advanced Study for Coastal Zone Oceanographic Requirements for Earth Resources Technology Satellites E & F." As I explained over the telephone, I am very much interested in this program because of the influence of climatic cycles on the abundance and availability of the more important commercial marine and estuarine species. These cycles also have very profound implications as far as aquaculture is concerned. It seems to me that there are two general periods which are going to be critical:

One is the rather long-term cycle which is described in the correspondence with Dr. Willett of M.I.T. and which is covered in the two publications enclosed as well as my summary of my studies during 1969 on fluctuations in abundance of marine species. I am presently working on one on sea scallop which, hopefully, will cover the period 1880-1970. There is one problem involved in the latter in that we do not have sea surface temperature records in Maine prior to 1905. I have done some work with New Haven air temperatures which go back to the middle 1700's, and these may be sufficiently related to the same cyclic pattern that they can be substituted.

As the descriptive term implies, long-term cycles -- that is, 20 years or more -- are of interest in forecasting future abundance trends of marine and estuarine species. In addition, it would be desirable to have information on short-term trends. I am not certain what period is likely to be the most valuable. I have some evidence that temperature changes from day to day are significant, but I have no array of data on this problem.

Mr. B. R. Loya

-2-

November 9, 1970

I have not used a shorter time interval than monthly temperature means, but I do believe that weekly observations probably will be quite valuable.

Another problem which is evident is the difference between surface temperature and bottom temperature. Is it going to be possible to infer bottom temperatures from observed surface temperatures? In the Gulf of Maine minimum surface temperatures occur in February. Minimum bottom temperatures, from observations made by departmental biologists working on the northern shrimp (Pandalus borealis) occur in late May or early June. Conversely, the maximum surface temperatures occur in August and maximum bottom temperatures in November or December.

This letter and the supporting documents serve more to outline my questions rather than any comments on the contents of ER TS E/F. I am sending it along so that you will be more fully cognizant of my ignorance before you telephone next.

Sincerely yours,



ROBERT L. DOW,  
Marine Research Director

RLD/jwu  
Enc.

State of California

THE RESOURCES AGENCY

## Memorandum

To : Mr. Edward D. Ehlers  
Department of Navigation  
& Ocean Development  
Room 1336, Resources Building  
Sacramento

Date : November 18, 1970

From : STATE WATER RESOURCES CONTROL BOARD

Subject: TRW Satellite Data User Survey

Any classification scheme that is used for information uses is arbitrary and the one provided by TRW relating to pollution is as arbitrary as any. The "Implied Information Needs" do not form mutually exclusive classes, but rather overlap in numerous cases. The "Associated Phenomena" are similarly overlapping classifications. As a result, it is impossible to determine whether omissions from the matrices in the User Survey are intentional in some locations.

The listings of "Environmental Measurables and Laboratory/Survey Efforts" refer in some cases to determinations of specific parameters and sometimes to studies of processes in the system. This is particularly true of the "Laboratory Studies..." column, which in Figures 1 & 2 is limited to rather specific analyses of parameters, but in Figures 3, 4 & 5 contains modeling and simulation studies and no parameter analyses. In Figures 6 & 7 the two types of information have been separated by adding a "Statistics" column and in Figure 9 the distinction between the two columns is not clear.

The data contained in the tables relating scale, accuracy and frequency of information have been filtered through remote sensing capabilities and are difficult to consider in terms of the basic pollution control program.

We are unable to provide the kind of evaluation requested by TRW in a reasonable time. It would require a discussion with them to determine what the matrices' contents really mean. I should note that Ocean Data Systems, although using a slightly different approach to the same problem, had the same result. There is a break in the logic between the definition of the phenomena and the derivation of the parameters needed.

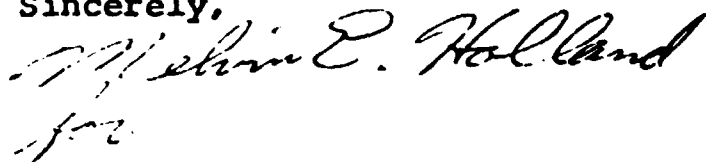
Mr. Edward D. Ehlers

-2-

The relative importance of the "Implied Information Needs" may be of value to TRW. For satellite sensing, the synoptic view is the primary value. Therefore, pollution location and cause and extent are of special significance. The rates of advance, cyclical variations and accumulation regions follow closely behind the extent. The effects on the marine ecosystem would be the main item from the effect class to be considered on the synoptic scale. Surveillance in optimal cleanup techniques is a secondary, but significant factor. While other needs listed may be significant, we do not recognize the significance of synoptic views of them.

I am sorry we cannot offer more detailed comments on the matrices. That would require more study than we are able to give to it at this time.

Sincerely,



ROBERT H. LEWIS  
Acting Chief  
Planning & Research Division

State of California

The Resources Agency

## Memorandum

To : Mr. Ed Ehlers  
Department of Navigation and  
Ocean Development  
Room 1336, Resources Building

Date: November 12, 1970

From : Department of Fish and Game

Subject: TRW Advanced Study - User Survey

The TRW user survey, dated October 9, 1970, was reviewed per your request. The present state of the art of fisheries management makes satellite observations of very limited use.

The proposal presumes that certain observations can be related to population dynamics of a particular species and, therefore, management of a fishery resource can be accomplished through more rapid data observations and transmittal. The error of this presumption is that many of the relationships that may be recorded by a satellite as yet have not been related to species abundance and, therefore, the gathering of these pieces of data, while of interest, would not enable us to manage a fishery.

There remains too many basic relationships which must be discovered before advanced data systems such as this would yield any usable product.

One additional thought is that the tuna or pelagic wetfish (mackerel anchovies) fishermen may have interest in the program if it will enable them to shorten their search time in locating fish schools.

  
Deputy Director

Telephone conversation with Ed Greenhood of The California Department of Fish and Game in Sacramento.

Ed Greenhood questioned certain of our relationships that appear in the survey documents. For example, we identify a need in our documents for information on larval survival success and we quote sea surface temperature as a directly applicable remote observable. He questions the present state of the knowledge in such relationships and suggests that if our charter is confined to consideration of an essentially operational satellite system, then we are in error to state at this time that obtaining sea surface temperature will provide the desired knowledge on survival of larvae. This also occurs in other places throughout the document. Another example that he pointed up was the direct spectral detection of fish schools. The relationship between spectral signatures and fish identity is indeed still in the preliminary research stage and, accordingly, spectral identification of fish in our document must fall into the category of research effort.

As a result of the above considerations the recommendation from Mr. Greenhood would be that we clearly identify those applications in which areas well known relationships exist and for which there would be little question as to the feasibility of surveillance in an operational sense. For those relationships that are still in the formative stages of understanding, the way in which the remote observables relate to the knowledge that we desire should be made clear. The mission relevancy portion of the study would appear to be the most likely spot to try to alleviate any such ambiguities.

Two of the major points that Ed Greenhood stressed regarding major problems in the next decade with relevance to fisheries and wildlife have to do with, (1) general water quality level of pesticides and pollution in our environment, (2) the effects of land modifications (especially on waterfowl). He felt that ironically the classical problems that have confronted fisheries, having to do with over-exploitation of fishable stocks, may be overshadowed by the fact that we are poisoning our environment. In other words the availability of fisheries stocks may be limited more by our activities as far as pollution is concerned than by over-exploitation.



November 17, 1970

Mr. B. R. Loya  
TRW Systems Group  
One Space Park  
Building R5, Room 2231  
Redondo Beach, California 90278

Dear Mr. Loya:

I must apologize for the delay in returning your survey material. Mr. Alverson reviewed the documents, but held up on returning them to you until I returned.

Our general and specific comments follow. Please telephone if you find some of the notes unclear.

#### General Comments on User Survey

Study is not restricted to coastal zone oceanography nor should it be. The data for fisheries which relates to the operations of the fishing vessels must be synoptic and must be obtained, processed, analyzed and the results (in simple terms) made available on a real time basis. For strategy related to supply, demand and price forecasts, the information and its analysis may lag somewhat and still be useful.

The major problem to be solved (if the space data program is initiated successfully) will be that of developing models to relate the complex information to fish and fishing.

The fishing industry was very poorly represented in the Marine Community Survey Group. L.M.R. showed the User Survey to a fishing captain, "Richie" Madruga, Captain of the M/V Conquest, and to Admiral Leslie Gheres, Manager of National Marine Terminal, operator of 12 tuna vessels, and Harold Cary, Vice President Planning at Westgate California, a seafood processing and marketing company. Their comments have been included in our notes.

Mr. B. R. Loya  
Page 2

To communicate with the fishing industry, it will be necessary to use fishing industry terminology and not space engineering jargon. The fishing industry is not engineering oriented to the same degree as is aerospace and there are some very good reasons for this:

1. There are no schools for fishermen and it is a trade which is learned at sea, generally begun after a high school (or less) education.
2. Successful skippers integrate all the observables in their head and make operating decisions on an experience and intuitive basis. There are so many factors involved and so little hard data that even a poor skipper can do better on the spot than a sophisticated model operated from shore without adequate input.
3. The engineers and systems analysts have already attempted and failed to assist the industry. Many of the operators are distrustful of such an approach because they do not understand it nor have they been shown results.
4. Processing company executives are largely from the old school also. There are few technically trained people in fish company management. Again, experience with Government, university and other industry experts has been poor. Most of the fishing industry progress has come from within.
5. The fishing industry is not peopled (as noted above) by people that communicate by written word, graph or flow diagrams. Almost all of the fishing industry operations which relates to the logistics of raw material acquisition by plants and fishing strategy by vessel operators is done verbally and in a different language than that used by engineers and systems people.
6. Government and university scientists, NASA and the aerospace companies will not change these conditions, so to be successful a system will have to adapt to the fishing industry.

The volume containing measurement requirements has been reviewed and the comments have been written on the appropriate pages. Under ground resolution in feet, we should comment that these values will depend on the fishery that is to be serviced. For example, surface schools of menhaden are very large and densely packed so that a ground resolution of 100 feet might be extremely useful (10 would be better) if the 10 feet were beyond the capability of the satellite technology.

Mr. B. R. Loya  
Page 3

We are assuming that mosaics could be constructed to widen the field of view of certain phenomenon. For example, the Mississippi River upstream activity and Gulf outflow would require a very broad picture, well beyond the view quoted.

#### Specific Comments on User Survey

#### 2.2 The Management of Perishable Coastal Resources - Fisheries

##### 2-15

1. Certain segments of the United States fleet are leaders in technology - shrimp, tuna.
2. "Catch per unit effort for various coordinated multi-platform tactics" - jargon and will not be understood. What about using "Vessel efficiency comparison among gears"?
3. Year class spawning success - poor term as the spawning is by the adult stock which is usually made up of several year groups. The resulting eggs, larvae, post-larvae, juvenile and then adult group is the year class. Year class success is related to parent stock size and to egg and larval survival.

##### 2-16

4. Volume estimates would be extremely valuable. At present, all methods of stock assessment are indirect and obtained from catch per effort statistics plus some depth sounder and sonar information.
5. Explained on comment sheet.
6. Weight and length data and reading of hard parts for rings (scales, otoliths, etc.) are all related to time in order to obtain growth curves.
7. Time and location and extent of spawning grounds relative to environmental conditions may be a key factor in egg and larval survival.

##### 2-17

8. Again, stock assessment in some direct manner would be of key importance.
9. Actually these two categories should be combined and the heading year class spawning success changed as noted in our comment 3.
10. Within the limits of economic fishing rates many stocks do not exhibit a parent - recruit abundance relationship. Shrimp is

Mr. B. R. Loya  
Page 4

an excellent example of a species that shows no correlation in these parameters and spawning success, egg and larval survival and growth are apparently related to environmental factors.

11. Yearly variations in sustainable yield. There is only one maximum yield as computed from the various models.

2-18

12. Prediction of production of raw material and its effect on the supply, demand equation is key factor here.
13. Unloading delays generally not a problem although better techniques could certainly be developed.
14. Fishing pressure is related to number of vessels, their efficiency, and that size portion of the stock they are exploiting. The measurables are total catch, total effort and catch per effort.

2-19

15. See comments on page made by Frank Alverson. Although all these comments and the data presented in the users survey are valuable, the boundaries of coastal oceanographic information have been extended to the offshore areas. If this study was truly a coastal and estuarine study, much of this would be of lesser concern.

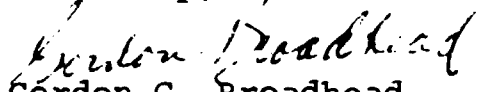
2-20

See comments on pages made by Frank Alverson.

2-21

Weather hazards for fishing vessels and weather limitations on fishing (not hazardous but reduce catching effectiveness) are very important to fisheries. Weather forecasting and two-way network to feed and receive information of this kind can form the basis for the operational strategy network which one would ultimately wish to operate. There are many barriers to the direct set-up of such a system. The best fishermen are not interested in raising the total catch, only theirs - raising the entire fleet efficiency through a grand plan will only result in their fish value being reduced (supply, demand, price). As most fishing vessels are independent units, it will require some incentive (weather information) to get a network structure established.

Sincerely,

  
Gordon C. Broadhead  
President

GCB/po

P.S. Survey material has been returned under separate cover.

B-2/

## **APPENDIX C**

### **Theoretical Basis For Dual Angle Dual Frequency Microwave Radiometer System**

## I. INTRODUCTION

The interpretation of data remotely sensed over the ocean require a sophisticated model of the emission and reflection of radiation from a rough sea surface. A theoretical basis for the radiative properties of a given surface was first provided by Peake,<sup>1</sup> who derived a relation between the brightness temperature and the electromagnetic scattering coefficients for the surface. Stogryn<sup>2</sup> has applied this relation to water surfaces by use of the scattering formalism generated with the approximate physical-optics<sup>6</sup> boundary fields. These results of brightness temperature versus observation angle demonstrated a marked sensitivity to wind speed (and, therefore, rms surface slope) for microwave frequencies, but the curves did not match the shape of experimental data,<sup>3</sup> and predicted temperatures were fifteen to twenty degrees below experiment. Clearly, a more thorough investigation was necessary if required temperature determination accuracies of one degree Kelvin were to be reached.

The TRW theoretical model discussed here is a complete geometrical-optics description of angular emissivity and electromagnetic scattering from randomly rough surfaces. That is, there is a basic restriction that the wavelength of interest be small compared with the characteristic scale lengths of the random process representing the surface, but the effects of surface shadowing and multiple scatter are included.<sup>4,5</sup> Both effects are absent in the Stogryn calculation, as well as in any analysis based on the physical-optics approximation. The neglect of shadowing results in an over-estimate of the effective surface area for scattering, and a shadow-corrected theory is a necessity if meaningful results are to be obtained for large observation angles (e.g., the Stogryn theory predicts negative brightness temperatures for large angles). The contribution to the scattering pattern due to multiple-scatter effects increases with increasing rms slope of the surface, and, dependent on polarization and angle of incidence, double scatter can be important even for relatively smooth surfaces. An additional feature of the TRW model is the temperature contribution due to a wind-driven spray layer just above the surface. The spray layer will modify, by absorption and emission, the intensity of radiation incident on, and scattered by, the sea surface. The TRW model

for brightness temperature of a two dimensional randomly rough surface has been programmed for the special case of a one-dimensional random rough surface (cylindrical symmetry), with the flexibility for parametric variations in frequency, polarization, observation angle, surface rms slope, water temperature, salinity, atmospheric water-vapor density, and sea-spray densities. The program has been run for a variety of combinations of these parameters and compared with experimental data. The results of these investigations are summarized below.

## II. SUMMARY

- 1) The existing theories of high-frequency rough-surface scattering and emission are limited in their validity to slightly rough surfaces and a restricted range of scattering angles. They are internally inconsistent (non-energy-conserving) because of the neglect of rough-surface shadowing and multiple-scatter effects, and their application to the ocean for realistic conditions can lead to not only inaccurate but even physically meaningless results.
- 2) A theory of shadowing of a randomly rough cylindrical surface was developed at TRW. Its generalized to a two-dimensionally rough surface, a geometrical optics theory of multiple scatter of electromagnetic radiation and the application of the more general scattering theory to the development of an improved theory of emissivity have all been accomplished at TRW. The new scattering and emission theories have been tested for the special case of cylindrical roughness and, in contrast to the existing theories, have been shown to be internally consistent (energy-conserving) and to be applicable to the sea under realistic sea and observation conditions.
- 3) A theorem was proved which established the existence, and method for calculation, of both upper and lower bounds to the true rough-surface emissivity. Thus the new theory provides not only a more accurate calculation of the emission temperature at high frequencies but also a means of calculating the maximum deviation of the computed value from the exact value of the emission temperature. In contrast, if the existing emission theories are used, not even rough estimates of the accuracy of the calculated values are possible.
- 4) The TRW model has been further extended to include the effects of a wind-driven spray layer on the observed brightness temperature. The spray model is an integral part of the theory and describes, via the radiative transfer equation, microwave emission by the layer as well as the attenuation of all radiation incident on, emitted from, and scattered by, the underlying sea surface.

5) To test the theory, sample calculations of sea brightness temperature were run for a one-dimensional surface roughness model. Based on the test calculations, the following conclusions were established:

- a) Except for calm seas and near-normal observation angles, the effects of surface shadowing and multiple scatter are extremely important; their neglect can result in errors far exceeding the tolerable limits.
- b) The upper bound to the exact emission temperature differs from the lower bound by a very small amount. Thus use of the new theory will permit highly accurate calculation of the effect of surface roughness on sea brightness temperature.
- c) The presence, at higher wind speeds, of a near-surface spray layer can substantially increase the observed brightness temperature; thus the inclusion of a spray layer as an integral part of the theory is a necessary requirement for a realistic sea brightness temperature model. Too little data exists, at present, on the physical properties of foam to warrant the development of a true theory of foam emissivity. Experimental evidence does indicate, however, that the contributions of foam to the brightness temperature can be significant. Thus semiempirical corrections, at least, are also required for a complete model.

6) The predictions of the complete one-dimensional geometric-optics model were compared with recent experimental measurements of brightness temperature over very rough seas. It was found that an excellent fit to the data (to within  $\sim 1^\circ\text{K}$ ) could be obtained for all angles, using physically reasonable values for those parameters (spray density, foam emissivity) for which no ground truth is available. Estimates of the theoretical brightness temperatures expected from the proposed complete two-dimensional roughness model indicate that an equally good fit to the data will be obtained using somewhat different, but still physically reasonable, values for the spray density and foam emissivity. The same experimental data was also compared with the predictions of the geometrical optics model of Stogryn and the "physical optics" model of Ulaby and Fung. The former disagreed with the data by  $\sim 30^\circ\text{K}$  and the latter by  $\sim 40^\circ\text{K}$ .

7) The development of a theory of double scatter on a two-dimensional randomly rough surface now permits the calculation of depolarization cross sections in high-frequency radar backscatter. The expected

sensitivity to surface roughness suggests depolarization measurements as a possible experimental technique for sea state measurement.

### III. STATUS OF THEORIES AND COMPARISON WITH EXPERIMENT

The three figures in this section show the comparison between measured sea brightness temperatures and the values predicted by the three existing theories of sea brightness temperatures. The experimental values shown on the graphs were recently reported by Nordberg, Conaway, Ross, and Wilheit, in "Measurements of Microwave Emission from a Foam Covered, Wind Driven Sea," October, 1970 (NASA Goddard preprint, submitted for publication to the Journal of Atmospheric Sciences). The measurements were taken over the North Sea and North Atlantic at 19.35 GHz using horizontal polarization; the reported data represents true brightness temperatures, with radiometer antenna characteristics fully accounted for. It was also stated that an absolute calibration correction requires all brightness temperature values quoted in the report to be increased by  $10-15^{\circ}\text{C}$ ; accordingly, the "experimental" curve on the accompanying graphs is exactly that reported by Nordberg (Figure 3, case F, of the referenced document) but with the brightness temperature values incremented by  $+15^{\circ}\text{C}$ . Case F represents low altitude observations over a very rough sea. The high wind speed (25 meters/sec) at the time of observation produced extensive "white water," as indicated by visual and photographic observation. The splash or foam created in the breaking of the waves is picked up by the wind and carried through the air, producing the large amount of white-water streaking observed at the time of measurement. The water carried by the wind is expected to be in two forms -- a high density of individual water droplets, producing a heavy spray layer, and "chunks" of foam torn off the tops of breaking waves. If this expectation is correct the total amount of foam contributing to the observed brightness temperature will be somewhat larger than the amount attributed to whitecaps (five percent area coverage); the balance of the total white water 37 per cent total area coverage) is then in the form of spray. The measurements established a brightness temperature of  $220^{\circ}\text{K}$  (corrected to  $235^{\circ}\text{K}$ ) for the white water. Clearly, a theoretical model for sea brightness temperature must explicitly account not only for surface roughness but for spray and foam as well.

In Figure 1, we show the brightness temperatures predicted by the Stogryn model (Trans. IEEE, AP-15, 278 (1967)) for a 25 m/sec wind, assuming the Cox and Munk relation between wind speed and surface roughness remains valid at this wind speed. The agreement with experiment is poor. At nadir ( $0^\circ$ ) the theoretical brightness temperature ( $T_B$ ) is too small; this is due principally to the neglect of both foam and spray in the model. For angles between 0 and 60 degrees the curve is much too flat; this may be shown to be the result of neglecting multiple scatter in the theory. Finally, at angles greater than 60 degrees the very steep drop in the theoretical curve is due to the neglect of rough surface shadowing effects.

In Figure 2, the brightness temperatures predicted by an emissivity model proposed by Ulaby and Fung (SWIEEEO Record of Technical Papers, p. 436, 1970) is compared with the NASA experiment. The parameter,  $C_0$ , which characterizes the surface roughness in this model was given the value of 81 to correspond to a 25 m/sec wind speed and a frequency of 19.35 HGz. The model includes neither spray nor foam. At nadir, the model predicts results which are in error by over  $40^\circ\text{C}$  (had foam and spray contributions been included, as they must, the error would be considerably larger). The multiplicative "antenna efficiency" factor,  $K$  ( $K \leq 1$ ), defined in the referenced paper, must be set equal to unity to compare with the measured values, since the data have reportedly already been corrected for the antenna characteristics. In the middle range of angles, the slope of the theoretical curve is approximately double that of the experimental curve. The increase in brightness temperature beyond  $\theta = 70$  degrees is due to refelected sky radiation, the rate of increase indicating nearly specular reflection — a rather peculiar result considering the extreme roughness of the surface. In addition to the extremely poor agreement with experiment, this model has no sound theoretical basis; the method of derivation (described by Fung and Chan, IEEE Trans., Peake, and Peake and Barrick (IEEE Trans., AP-18, 716-725, 1970). Furthermore, some years ago we investigated an almost identical model and concluded that the inconsistencies in the theory were sufficiently serious as to render it totally useless for the precise description required to interpret data in terms of the physical properties of the sea.

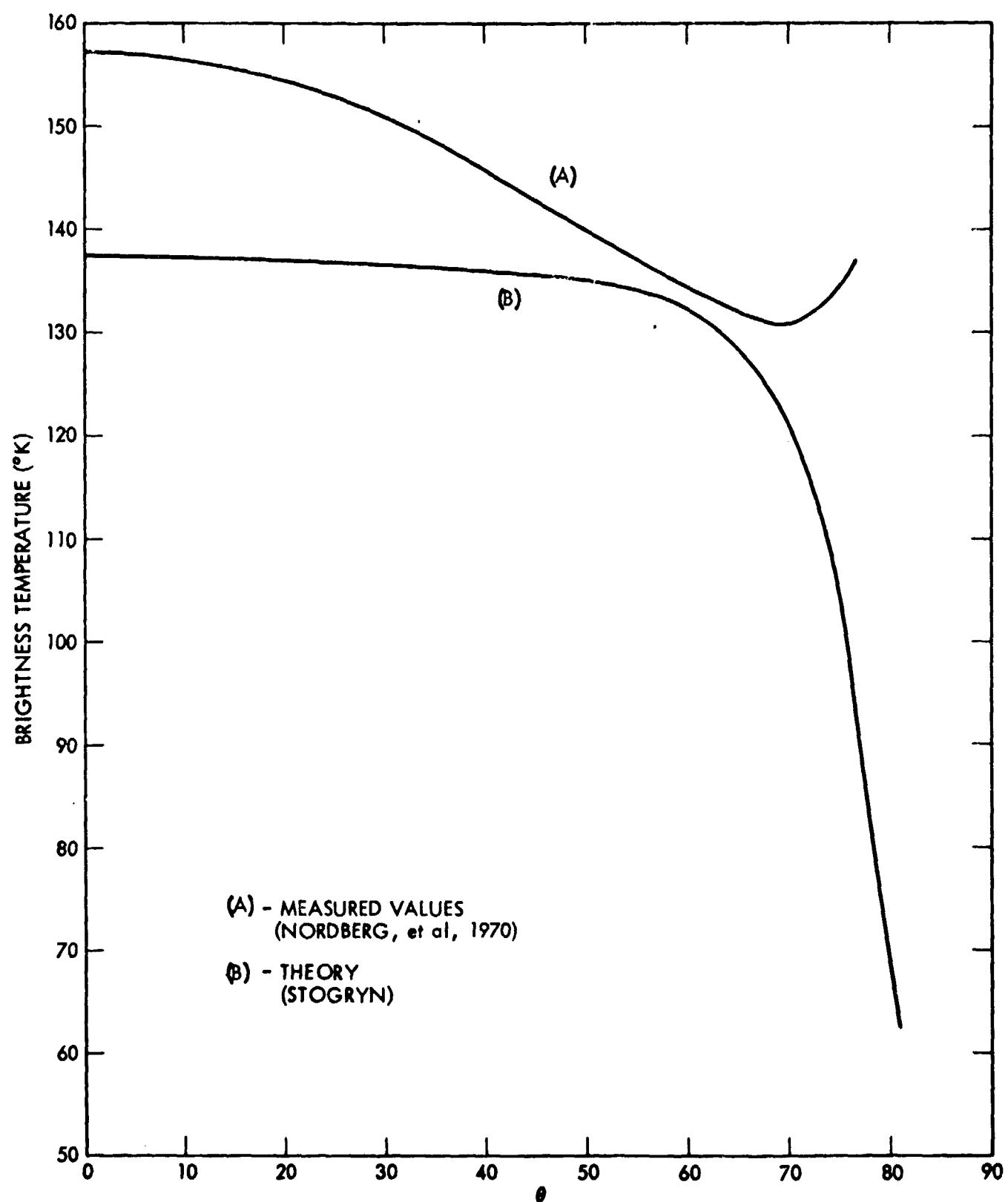


Figure 1. Comparison of experiment with theory of Stogryn for a frequency of 19.35 GHz, horizontal polarization, and wind speed of 25 m/sec

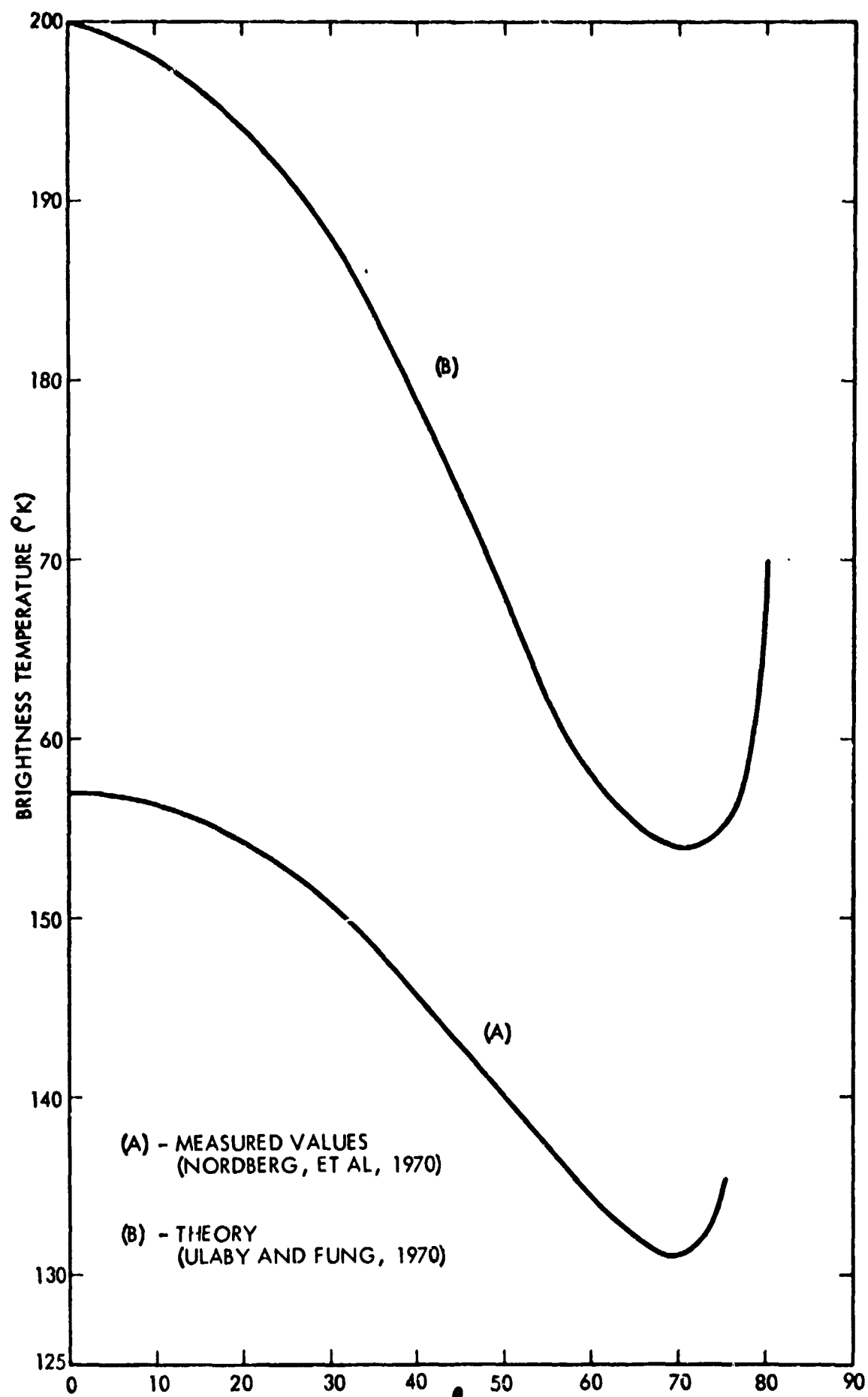


Figure 2. Comparison of experiment with theory of Ulaby and Fung for a frequency of 19.35 GHz, horizontal polarization, and wind speed of 25 m/sec

In Figure 3, the same NASA Goddard data is compared with the values predicted by the model of Wagner and Lynch. The model is based on a theory of surface roughness effects which includes both rough-surface shadowing and multiple-scatter effects for a cylindrical roughness model; the attenuative and emissive properties of a wind-driven spray layer are an integral part of the model. The theoretical curve shown in Figure 3 was based on numerical results computed some time ago for a set of values of surface roughness, water and spray temperatures, and atmospheric temperatures and humidities. The parameters used in the computations do not coincide precisely with the ground truth values provided by Nordberg, et al. In this sense the theoretical curve does not represent a "best fit" to the data. The actual parameters used in the theoretical curve of Figure 3 are as follows: frequency = 19.35 GHz, horizontal polarization, water temperature = spray temperature =  $283^{\circ}\text{K}$ , sea level atmospheric water vapor density of  $8\text{ g/m}^3$ , air temperature of  $290^{\circ}$ , and foam brightness temperature of  $235^{\circ}\text{K}$ . An rms surface slope equal to  $\tan 20^{\circ}$  was used which, for a cylindrical roughness model, corresponds to a wind speed of approximately 25 m/sec. An attenuation coefficient through the spray layer of 0.17 db is assumed, corresponding, at this frequency, to an average spray rate of 4.5 inches of water per hour over a layer 10 meters thick (or 2.25 inches per hour in a 20 meter thick layer, etc.). In other words, if a rain gauge were positioned horizontally anywhere within 10 meters from the mean surface it would collect an average of 4.5 inches of water in one hour. No data on the actual spray density is available but judging from the heavy streaking visible in the photographic measurements the spray rate is evidently quite high. The spray rate assumed in the theoretical model is believed to be at least not unreasonable.

Finally, the contribution of foam has been included. Foam is generated by the breaking of waves which occurs with increasing frequency as the wind speed increases. The data of Nordberg, et al., show an increase in the fraction of the total surface area covered by whitecaps from 0 to 7% as the wind speed increased from 6 m/sec to 13 m/sec; at higher wind speeds this fraction then dropped to 5%. This decrease is believed to be the result, not of fewer breaking waves (which is most

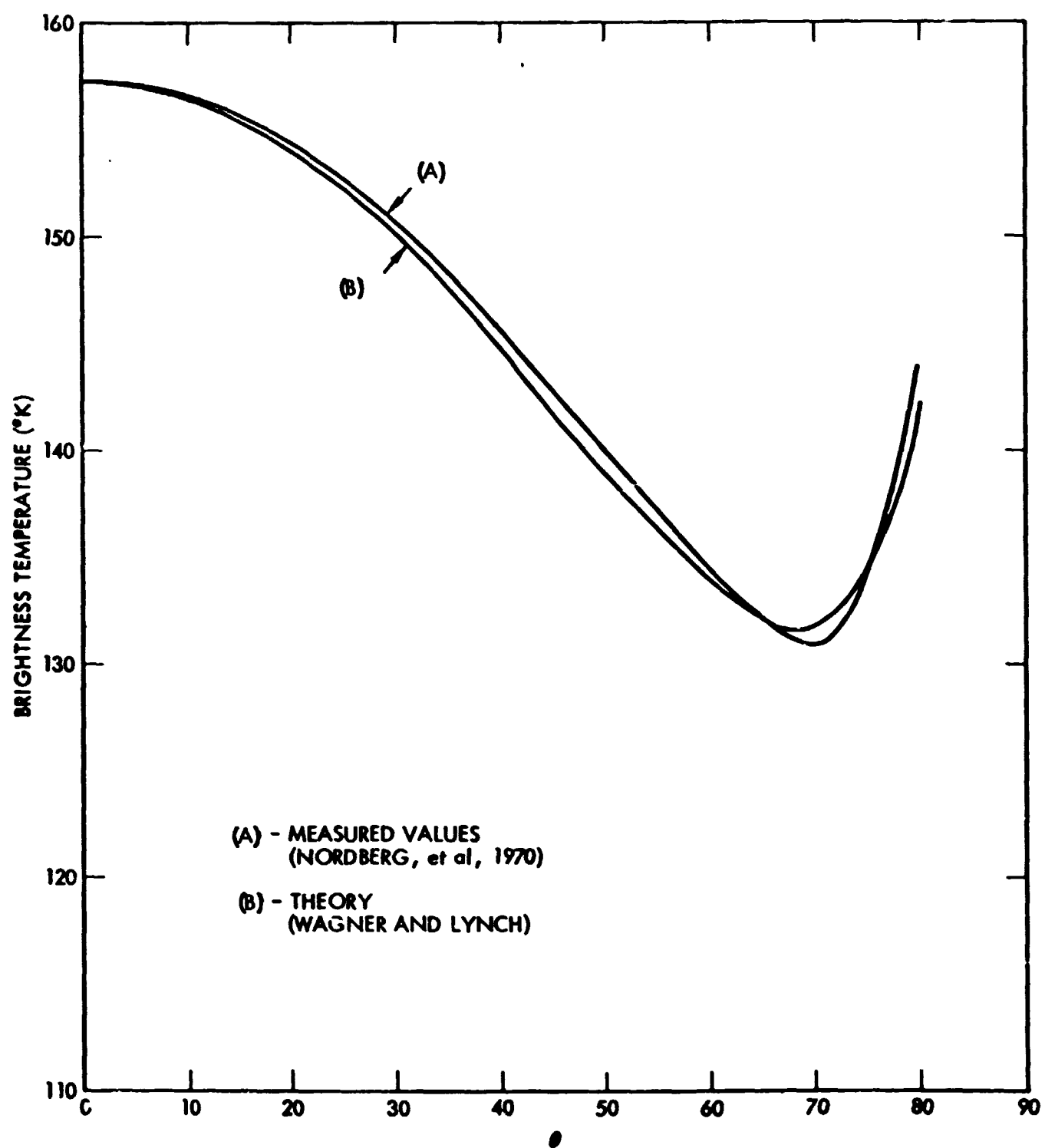


Figure 3. Comparison of experiment with theory of Wagner and Lynch for a frequency of 19.35 GHz, horizontal polarization, and wind speed of 25 m/sec

unlikely), but of the tearing off of the tops of the breaking waves by the very high winds. Thus foam generated in the breaking process will no longer appear as whitecaps but will be carried by the wind and contribute to the observed streaking. Before the wind-carried foam breaks up into water droplets to form the spray layer, it will exist for a time in bulk form. Thus to the observed 5% foam (whitecap) coverage should reasonably be added the amount of bulk foam carried along with the spray layer. We have assumed a total of 15% area coverage, on the average, due to foam (with the balance, 22%, of the observed white water ascribed to water in spray droplet form). Again, the accuracy of this estimate is not known but is believed to be not unreasonable. The angle dependence of the emissivity of foam is not known experimentally. Optical observation of foam would indicate it to be a very diffuse, essentially Lambertian, emitter. However, at a radiation wavelength of 1.5 cm, the bubble structure of the foam will be almost entirely smaller than a wavelength and an emissivity characteristic of a less diffuse surface would be expected. Thus, an angle dependence of  $\cos \theta$  was chosen for the emissivity. Since a single foam patch is much smaller than the radiometer beam diameter the brightness temperature contains an additional factor of  $\cos \theta$  arising from the projection of the area of the patch in the direction of the beam, leading to a total angle dependence of  $\cos^2 \theta$  for the foam contribution.

The brightness temperature of pure foam, taken to be  $235^\circ\text{K}$  viewed at nadir, was then weighted by 0.15 (the foam fractional area coverage) and added to the predicted brightness temperature of the spray-covered rough sea, weighted by 0.85, to arrive at the theoretical curve shown in Figure 3. The agreement with the experimental values is excellent. The maximum deviation between theory and experiment is about  $1^\circ\text{C}$ . In comparison, for observation angles between  $\theta = 0^\circ$  and  $75^\circ$ , the Stogryn model is in error by as much as  $30^\circ\text{C}$ , while the errors in the Ulaby and Fung model exceed  $40^\circ\text{C}$ .

#### IV. DETERMINATION OF SEA TEMPERATURE AND SEA STATE

Based on the TRW theoretical studies, a technique for accurate radiometric measurement of sea temperature and sea state has been developed. The procedure, as presently formulated, requires observations at 2 frequencies, 2 angles, and a single polarization; in most steps of the measurement process, only differences in brightness temperatures are required, thus minimizing errors introduced by the (highly probable) absolute calibration errors of the instrument.

Frequencies of 19 and 10 GHz (vertically polarized) and angles of  $40^\circ$  and  $60^\circ$  from the vertical are suggested; although the exact values of these parameters are not important there are reasons for choosing them in the general neighborhood of the values indicated. In the computer runs made for the illustration which follows, 19.35 and 9.3 GHz were actually used.

The general Procedure is as follows:

- 1) The vertically polarized brightness temperatures at 19.35 GHz and 9.3 GHz are measured at an angle of  $60^\circ$  and again at  $40^\circ$ ; for each frequency the difference of the temperature,  $\Delta T_{60,40} \equiv T(60^\circ) - T(40^\circ)$ , is formed.
- 2) A "guess" is made of the lowest,  $T'$ , and the highest,  $T''$ , water temperatures likely to occur in the region of ocean being observed.
- 3) The value of  $\Delta T_{60,40}$  at 9.3 GHz and the pair of temperatures  $T'$ ,  $T''$  then determine a corresponding pair of values of rms surface slope  $s'$ ,  $s''$ . The values of  $s'$ ,  $s''$  may be shown to be independent of atmospheric water vapor content and the presence of a wind-driven spray layer.
- 4) From the measurement of  $\Delta T_{60,40}$  at 19.35 GHz and the two sets of values  $(T', s')$ ,  $(T'', s'')$  so far determined, one can deduce a corresponding pair of values  $\rho'$ ,  $\rho''$  of atmospheric water vapor content (or sea level water vapor density, in the case of a standard atmosphere). The values of  $\rho'$ ,  $\rho''$  are also independent of the presence of a spray layer.
- 5) Using the 9.3 GHz measurement of either  $T(40^\circ)$  or  $T(60^\circ)$  and the two sets of values  $(T', s', \rho')$ ,  $(T'', s'', \rho'')$ , two new values of water temperature  $T_w'$ ,  $T_w''$  can be determined. The smaller of these values is then a new minimum and the larger a new maximum water temperature;

according to our numerical results they will lie much closer together than the original estimates  $T'$ ,  $T''$ . If they differ by a sufficiently small amount then the true water temperature has been determined; in addition, the surface roughness (or wind speed) and atmospheric water vapor content are also bracketed by the values of  $(s', s'')$  and  $(\rho', \rho'')$ .

6) If  $|T_w'' - T_w'|$  is not sufficiently small, then  $T_w'$  and  $T_w''$  are taken to be new estimates of the minimum and maximum water temperatures, and steps (1) through (5) are repeated.

We illustrate the method with a specific example:

1) Assume the measurement has provided the following data:

$$\text{at } 19.35 \text{ GHz: } \Delta T_{60,40} = 35^\circ \text{K}$$

$$\text{At } 9.3 \text{ GHz: } \Delta T_{60,40} = 40^\circ \text{K and } T(40^\circ) = 138^\circ \text{K}$$

Suppose also that, at the time of observation, the water temperature almost certainly lies between  $10^\circ \text{C}$  and  $20^\circ \text{C}$ ; i.e.,  $T' = 283^\circ \text{K}$ ,  $T'' = 293^\circ \text{K}$ .

2) From Figure 4, we see that if the water temperature is as low as  $283^\circ \text{K}$  then the observed temperature difference at 9.3 GHz ( $\Delta T_{60,40} = 40^\circ \text{K}$ ) can result only if the rms surface slope angle is  $10^\circ$ . If the water is as warm as  $293^\circ$ , the value  $\Delta T_{60,40} = 40^\circ$  can occur only if the rms surface slope angle is  $11^\circ$ .

The dependence of the slope determination on atmospheric water vapor, at 9.3 GHz, is illustrated in Figure 5. This shows how one of the curves of Figure 4 (curve b) changes for two extreme values of water vapor density - very dry air ( $\rho = 0 \text{ g/m}^3$ ) and very humid air ( $\rho = 20 \text{ g/m}^3$ ). The difference, even for these extreme values, is negligible.

3) The pair of values  $(T', s') = (283^\circ \text{K}, 10^\circ)$  and the measured value  $\Delta T_{60,40} = 35^\circ \text{K}$  at 19.35 GHz locates a point on Figure 6 through which will pass one of the family of curves corresponding to different atmospheric water vapor densities (3 are shown on the graph); this determines the value of  $\rho'$ . Similarly,  $\rho''$  can be determined from Figure 7 using the pair of values  $(T'', s'') = (293^\circ \text{K}, 11^\circ)$ . Actually the determination of  $\rho'$ ,  $\rho''$  is better accomplished by using Figure 8 which was obtained by

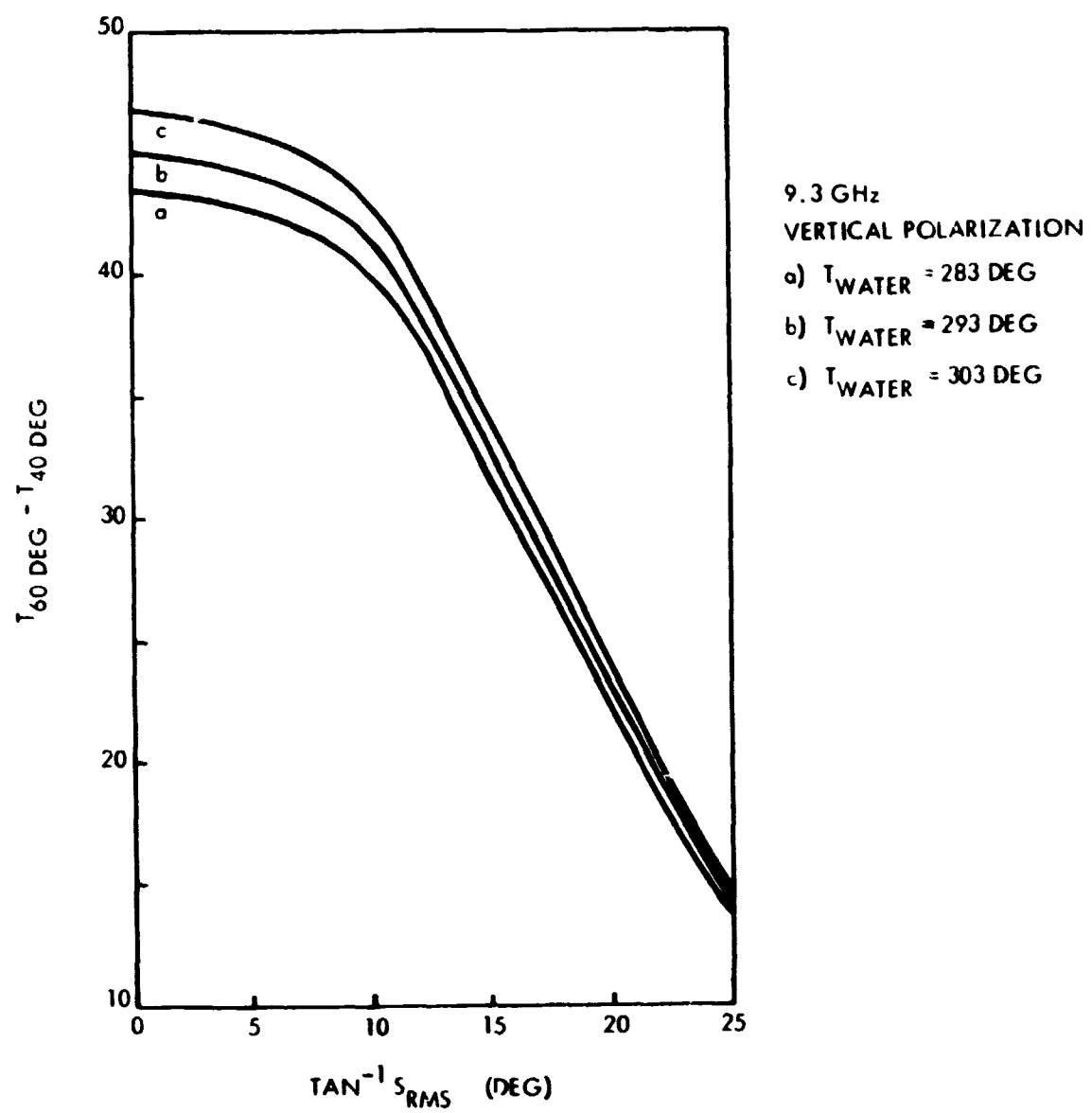
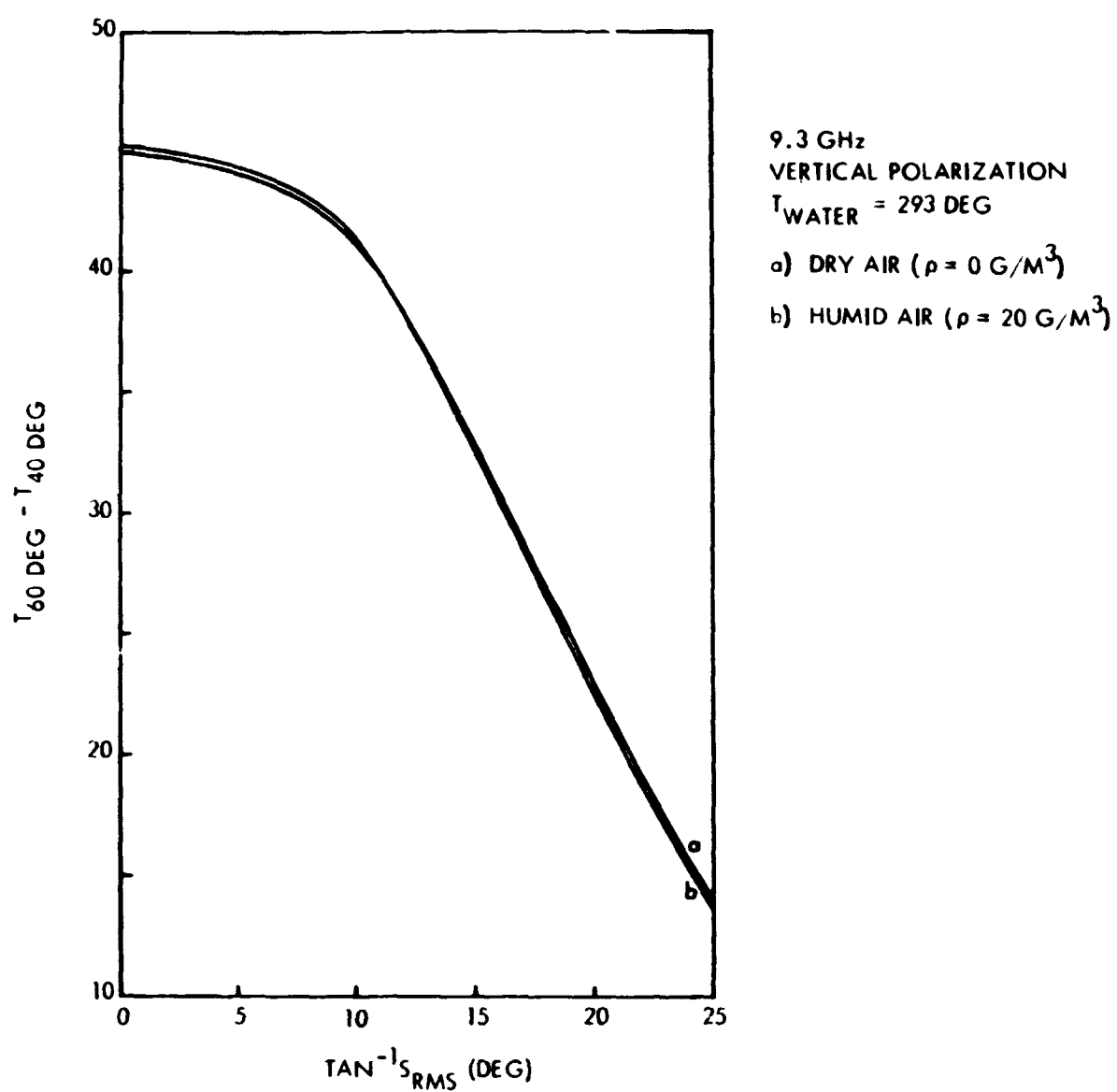


Figure 4. The difference in sea brightness temperature, measured at angles of 60 and 40 degrees from the normal, as a function of surface roughness and water temperature for a frequency of 9.3 GHz and vertical polarization. The surface roughness is represented by the arctangent of the rms surface slope.



**Figure 5.** The difference in sea brightness temperature, measured at angles of 60 and 40 degrees as a function of surface roughness for a water temperature of 293°K. Curves (a) and (b) represent the extreme cases of very dry and very humid atmospheres and demonstrate the independence of the curves of Figure 4 on atmospheric water vapor.

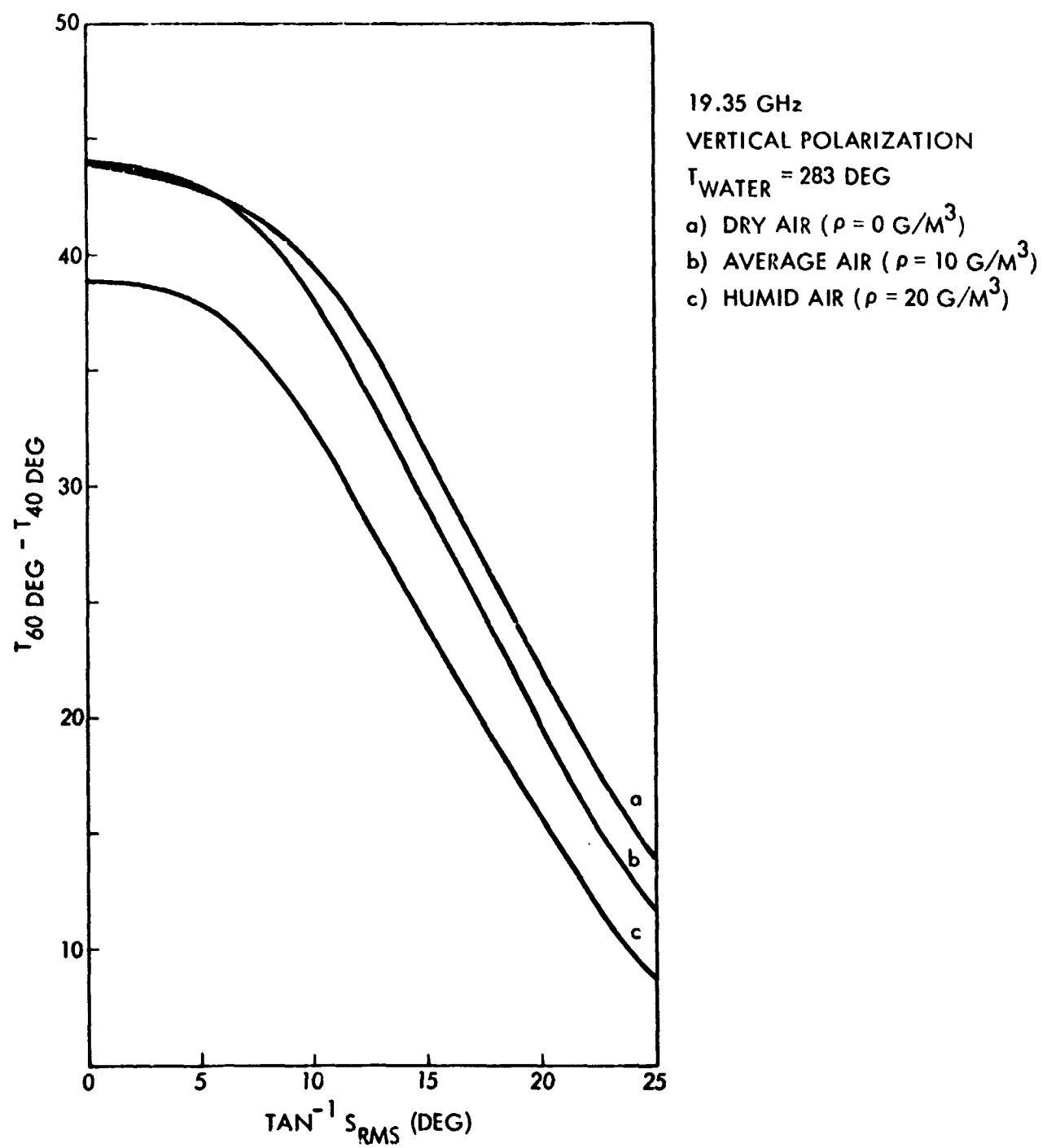
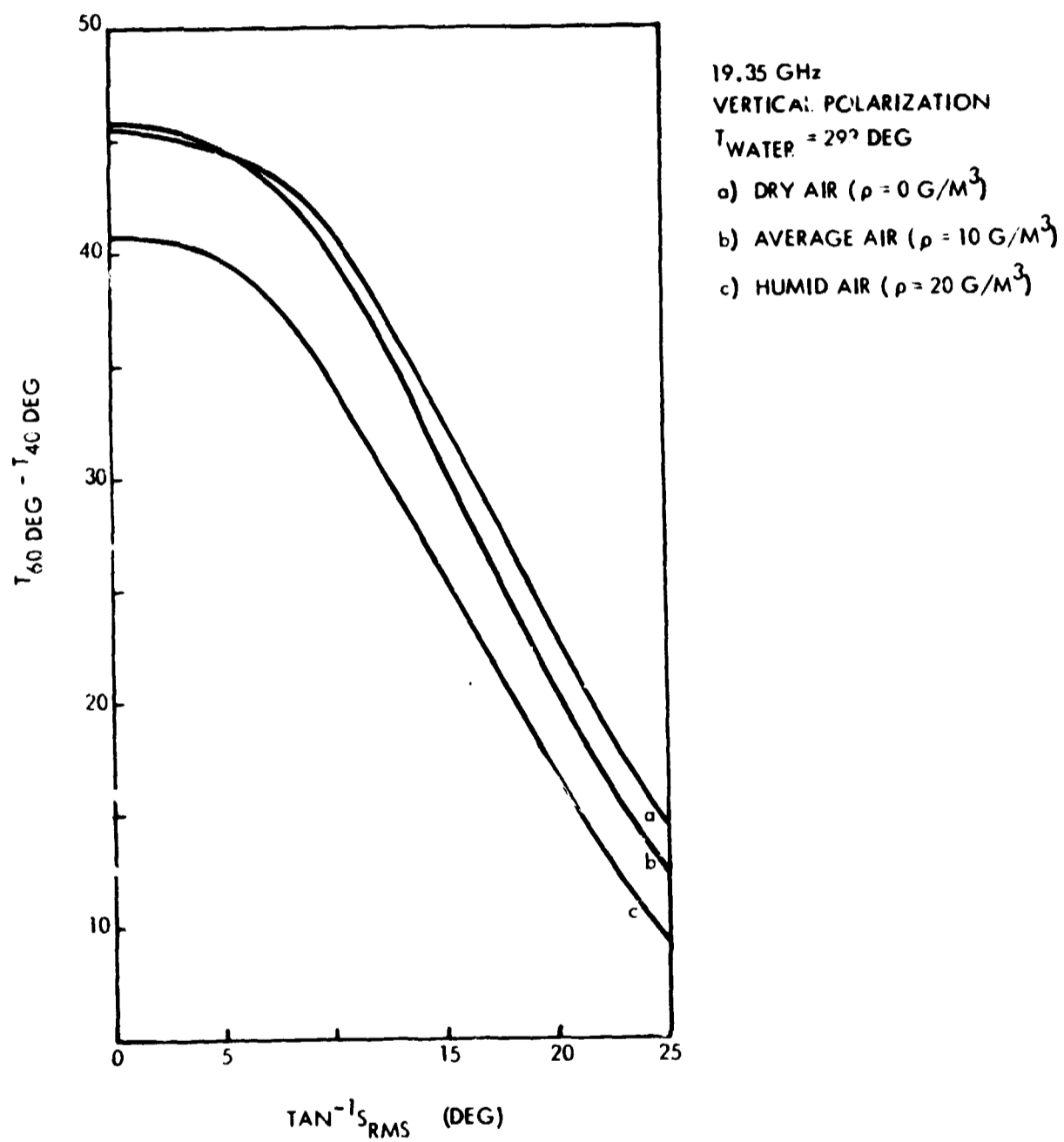


Figure 6. Vertically polarized brightness temperature differences, at angles of 60 and 40 degrees and 19.35 GHz, as a function of surface roughness and atmospheric water vapor density; the temperature of the sea water is 283°K.



**Figure 7.** Vertical polarized brightness temperature differences, at angles of 60 and 40 degrees and 19.35 GHz, as a function of surface roughness and atmospheric water vapor density; the temperature of the sea water is 293°K.

cross-plotting from Figures 6 and 7 and using  $\Delta T_{60,40} = 35^\circ\text{K}$ . From Figure 8 we find  $\rho' = 16.15 \text{ g/m}^3$  and  $\rho'' = 16.75 \text{ g/m}^3$ .

(4) Figures 9 - 14 are a set of six graphs, one for each of six values of surface roughness, showing the relation between true and apparent water temperature at 9.3 GHz and an observation angle of  $40^\circ$ . For the values  $(s', \rho') = (10^\circ, 16.15)$  one would use Figure 11 and the measured value  $T(40^\circ) = 138^\circ\text{K}$  to determine the new estimate of the true water temperature,  $T_w'$ ; similarly, Figure 12 could be used to determine  $T_w''$  from  $(s'', \rho'') = (11^\circ, 16.75)$ . To avoid interpolating on the families of curves for different water vapor densities, however, it is more convenient to use Figure 15, obtained from Figures 11 and 12 for the measured value  $T(40^\circ) = 138^\circ\text{K}$ . Corresponding to  $(s', \rho') = (10^\circ, 16.15 \text{ g/m}^3)$ ,  $(s'', \rho'') = (11^\circ, 16.75 \text{ g/m}^3)$ , we find  $T_w' = 287.65^\circ\text{K}$ ,  $T_w'' = 286.15^\circ\text{K}$ , respectively. We therefore conclude that the water temperature, surface roughness (rms slope angle), and atmospheric water vapor density have the values

$$T_w = 286.9 \pm .75^\circ\text{K}$$

$$s = 10.5 \pm 0.5^\circ$$

$$\rho = 16.45 \pm 0.30 \text{ g/m}^3.$$

(5) If more accurate values of  $T_w$ ,  $s$ , and  $\rho$  are desired one would repeat the above procedure assuming, for the new estimated minimum and maximum water temperatures, the new values  $T' = 286.15^\circ\text{K}$ , respectively.

Salinity of the sea water also appears accessible to unique measurement but a lower frequency is, of course, required. The lowest frequency we used in our numerical calculation was 3.0 GHz; with this frequency the principle of the measurement procedure can be established but adequate sensitivity to salinity will require a lower frequency. The procedure is based on our observation that the difference between the measured apparent temperature at 9.3 and 3.0 GHz, measured at any convenient angle, is essentially independent of atmospheric water vapor content, water temperature, and surface roughness, but does depend on salinity. The sensitivity of the difference measurement to salinity and its independence of other environmental parameters will be investigated for the 9.3 and 1.0 GHz combination in the near future.

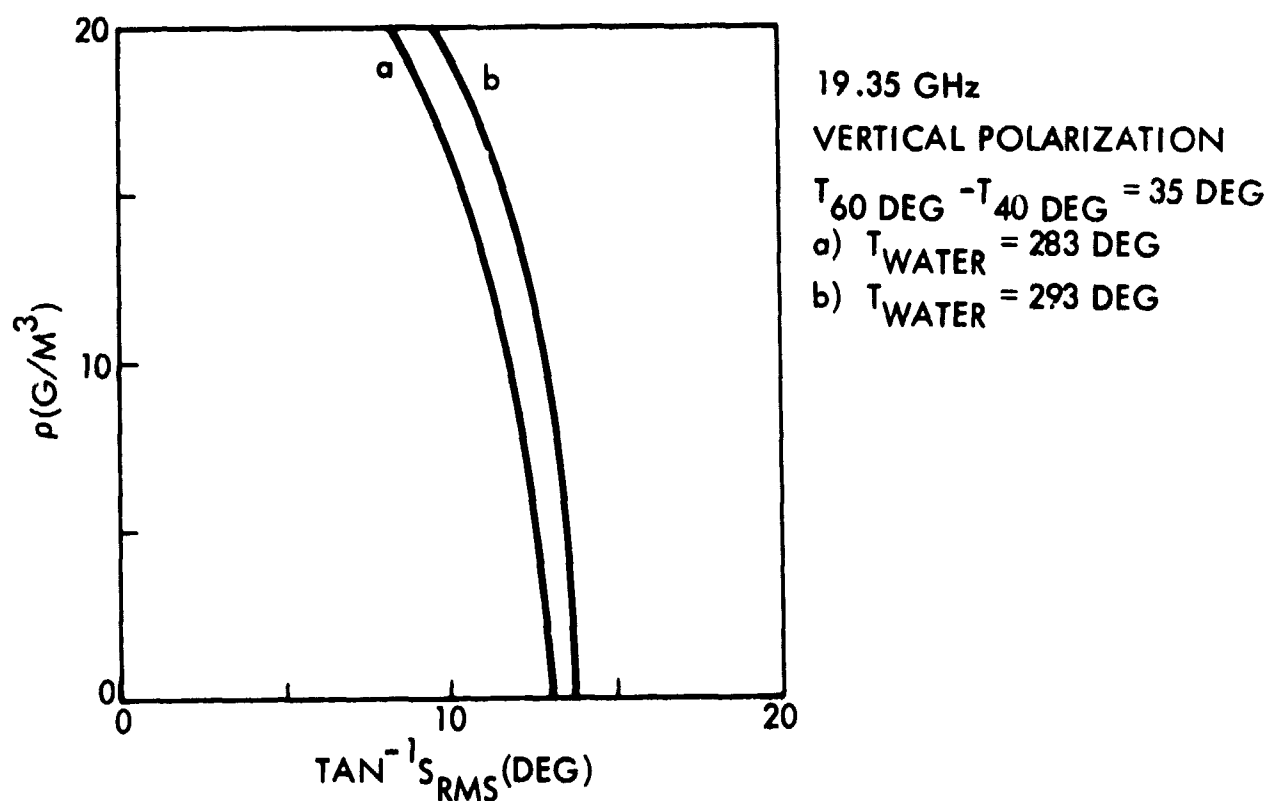


Figure 8. The values of atmospheric water vapor density which, for a given sea slope angle and a water temperature of 283 or 293°K, correspond to an observed temperature difference of 35°K at angles of 60 and 40 degrees.

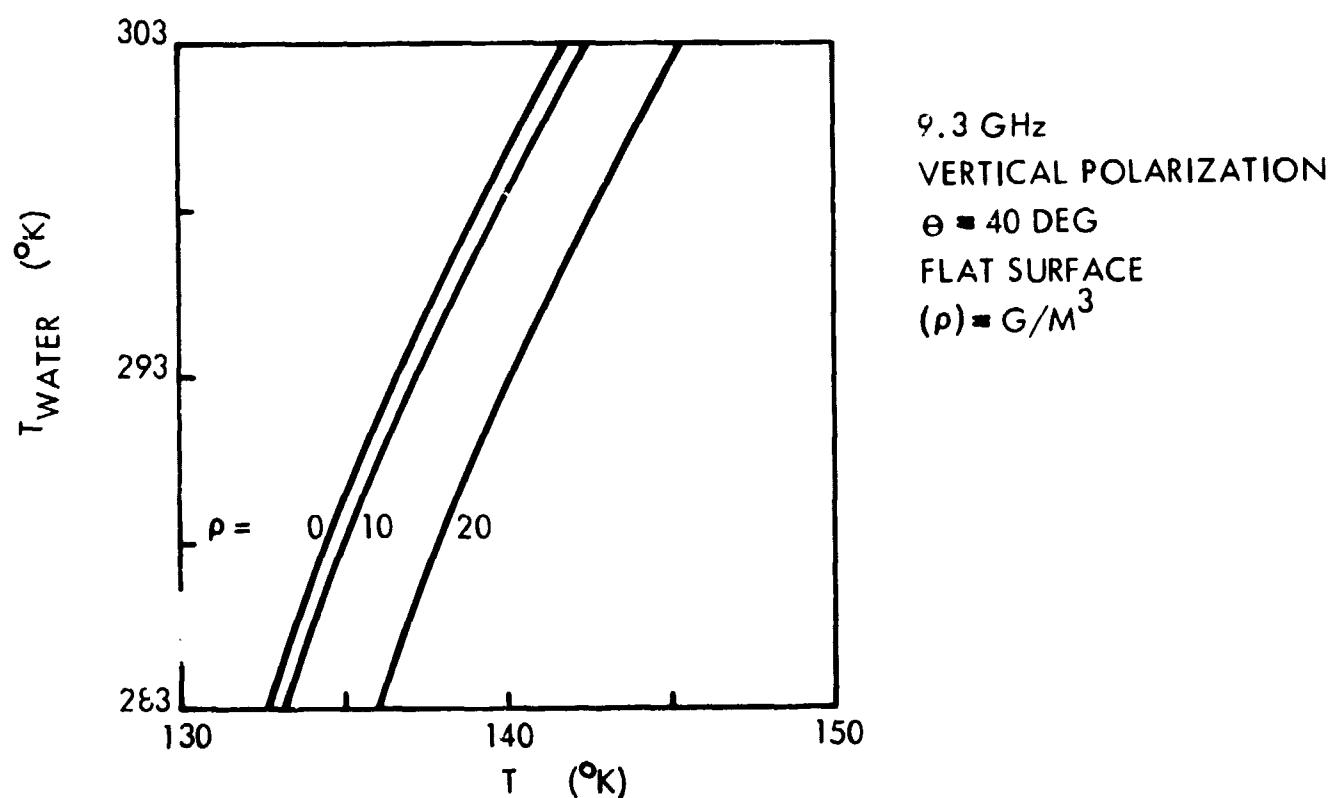


Figure 9. The relationship between apparent and true water temperature for atmospheric water vapor densities of 0, 10, 20 g/m<sup>3</sup>, for a surface with rms slope angle of 0 degree, and an observation angle of 40 degrees.

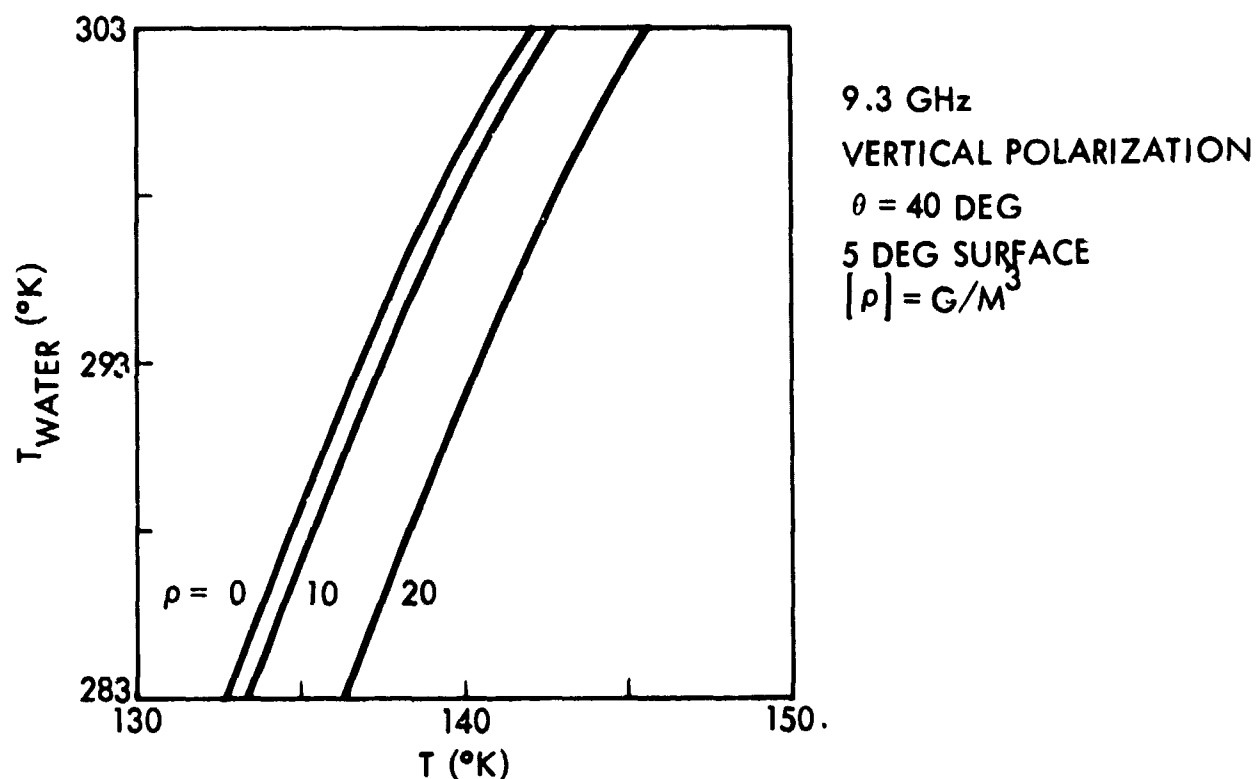


Figure 10. The relationship between apparent and true water temperature for atmospheric water vapor densities of 0, 10, 20  $\text{g/m}^3$ , for a surface with rms slope angle of 5 degrees, and an observation angle of 40 degrees.

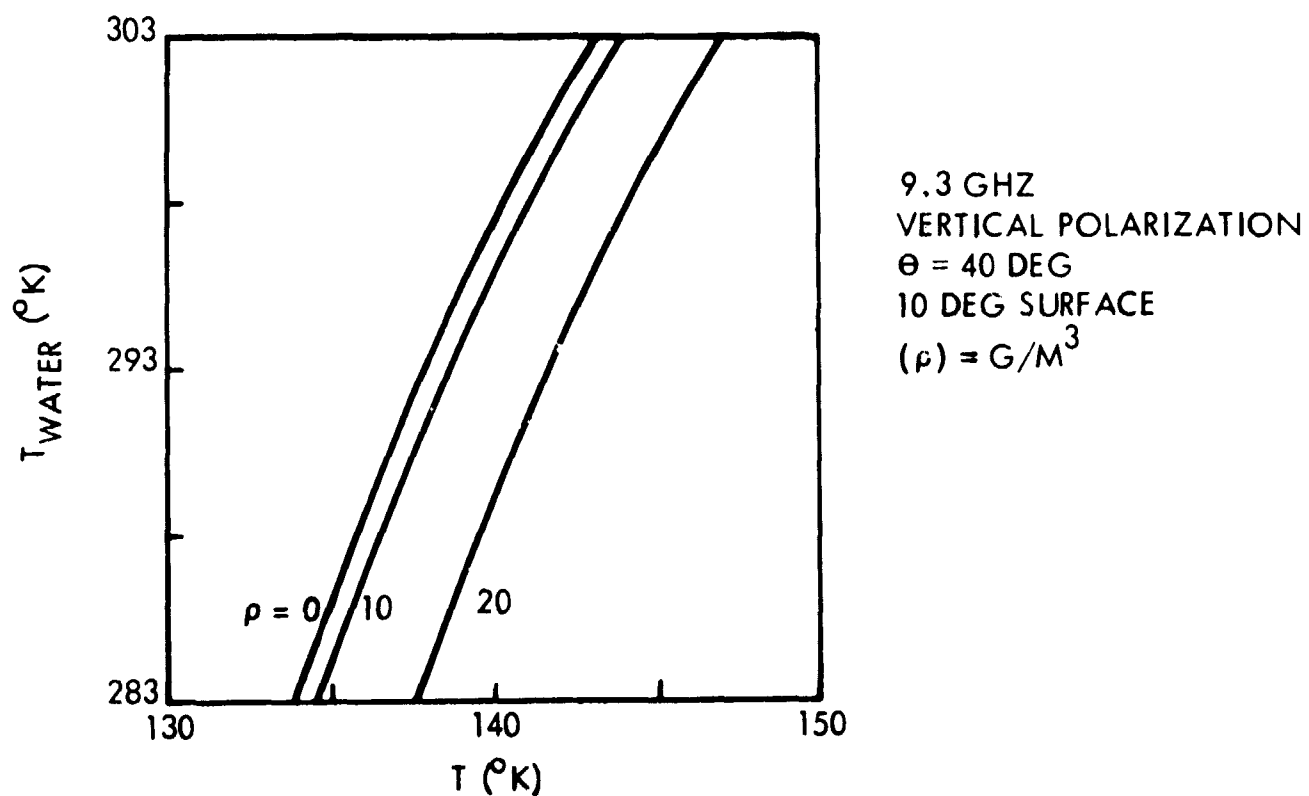


Figure 11. The relationship between apparent and true water temperature for atmospheric water vapor densities of 0, 10, 20  $\text{g/m}^3$ , for a surface with rms slope angle of 10 degrees, and an observation angle of 40 degrees.

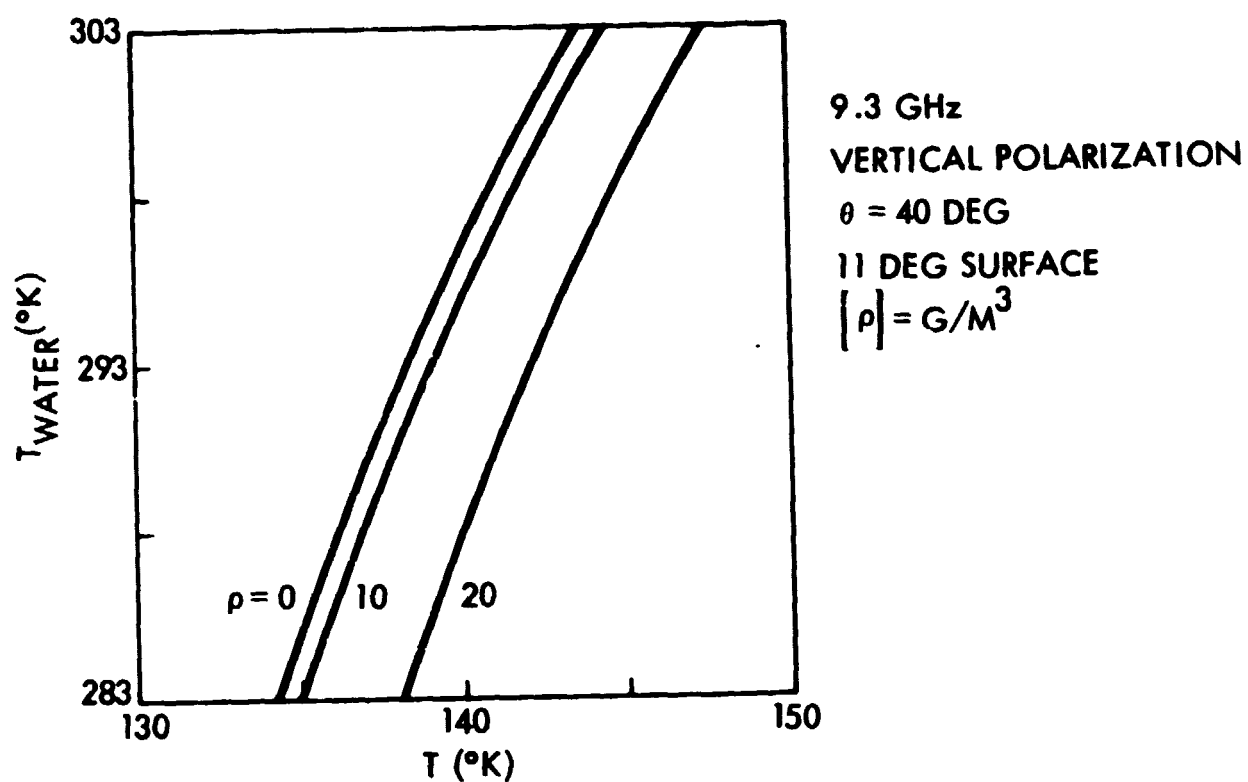


Figure 12. The relationship between apparent and true water temperature for atmospheric water vapor densities of 0, 10, 20  $\text{g/m}^3$ , for a surface with rms slope angle of 11 degrees, and an observation angle of 40 degrees.

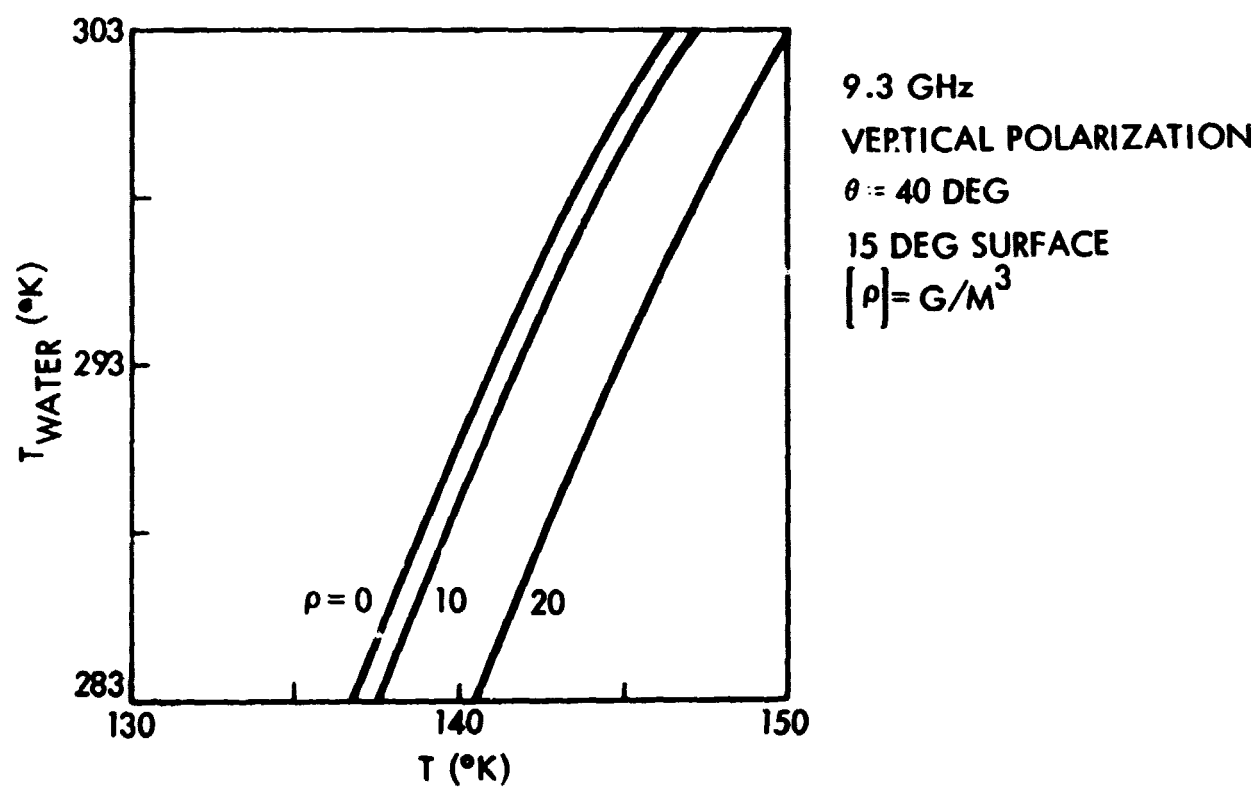


Figure 13. The relationship between apparent and true water temperature for atmospheric water vapor densities of 0, 10, 20  $\text{g/m}^3$ , for a surface with rms slope angle of 15 degrees, and an observation angle of 40 degrees.

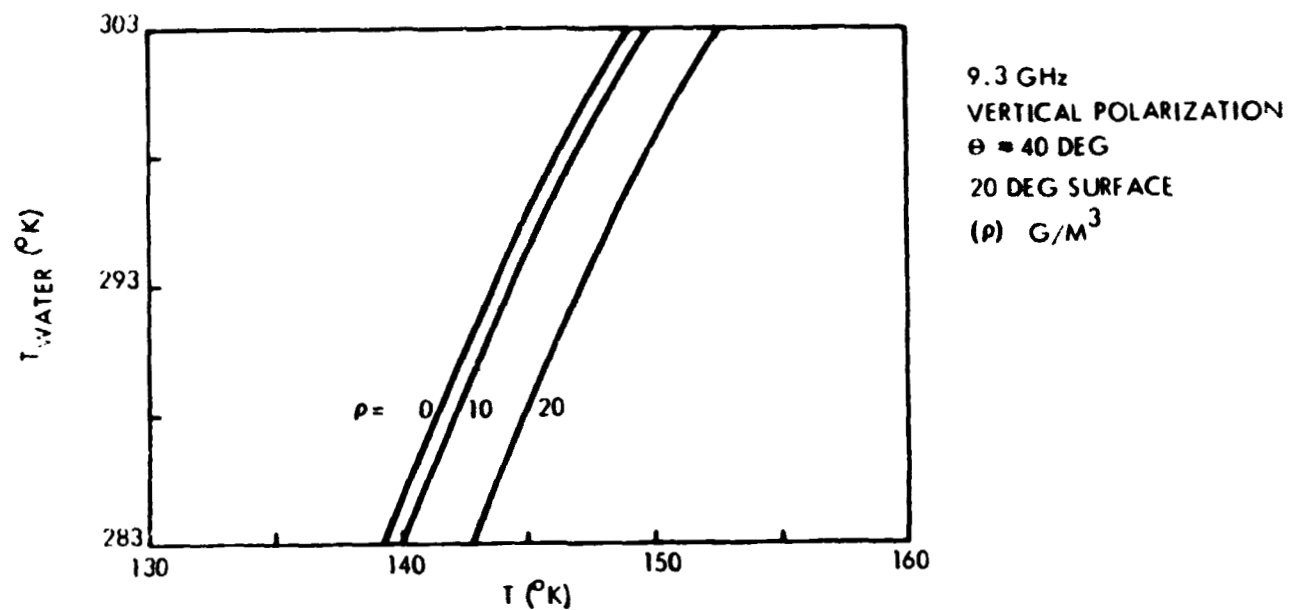


Figure 14. The relationship between apparent and true water temperature for atmospheric water vapor densities of 0, 10, 20 g/m<sup>3</sup>, for a surface with rms slope angle of 20 degrees, and an observation angle of 40 degrees.

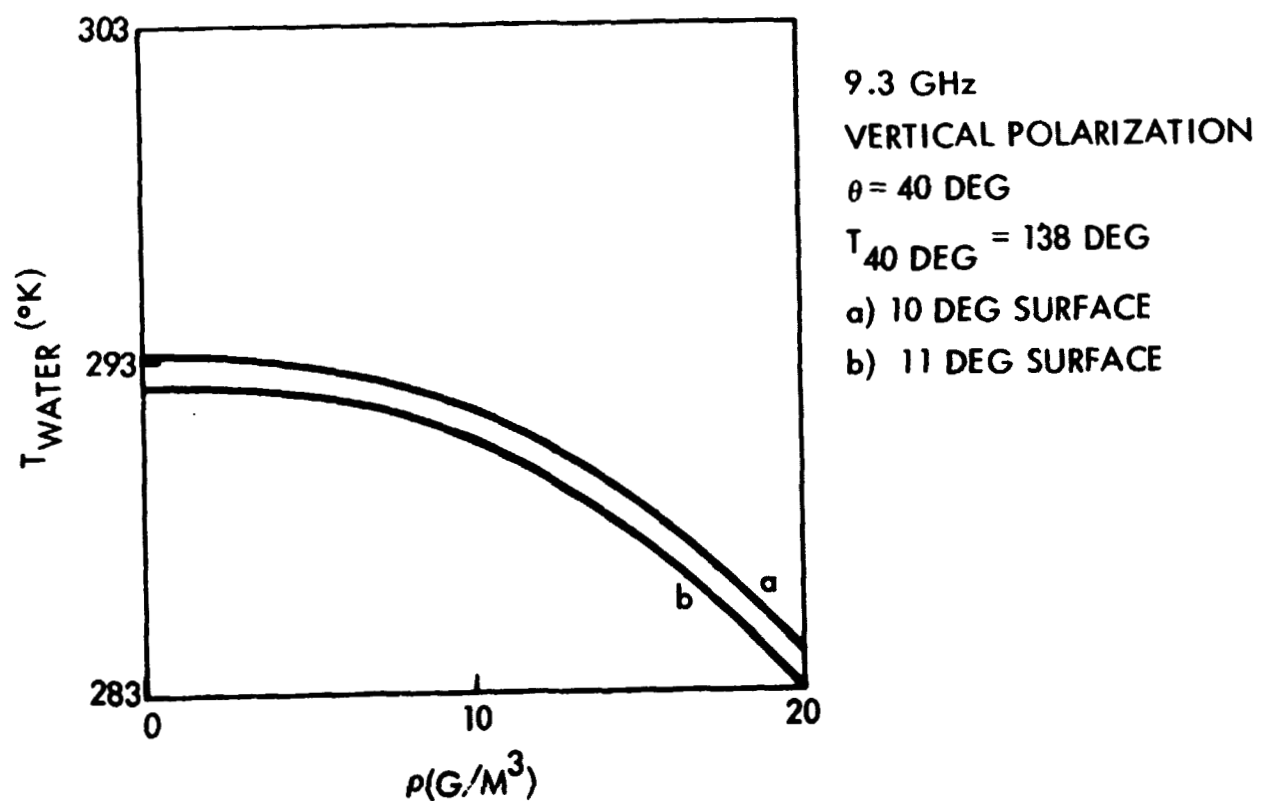


Figure 15. The temperature of sea water which will produce an observed apparent temperature of 138°K, as a function of atmospheric water vapor density, for sea slope angles of 10 and 11 degrees; the observation angle is 40 degrees from the nadir.

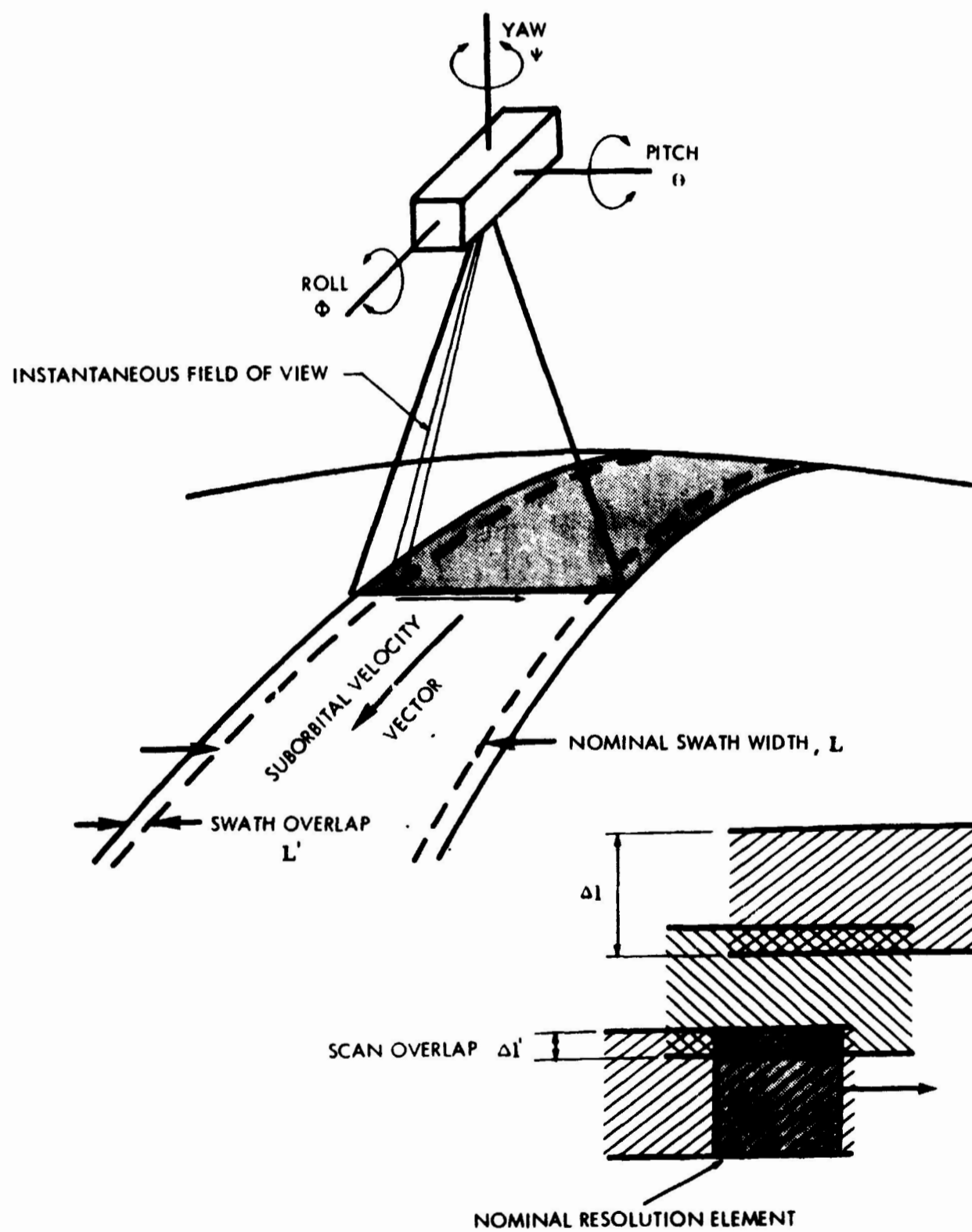
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## **APPENDIX D**

### **SPACECRAFT POINTING REQUIREMENTS**

## SPACECRAFT POINTING REQUIREMENTS

Since several candidate sensors utilize crosstrack line scanning combined with the spacecraft forward velocity to form a strip map image, the effects of spacecraft attitude control must be considered. It is assumed that absolute spacecraft attitude is accurately known from on-board references so that spatial elements can be repositioned during ground reconstruction of the image to remove distortions. Attitude reference accuracy requirements are dependent on spatial resolution and the tolerable distortions for the specific application. It is much easier to measure attitude errors and remove them from the data than attempt to precisely point the spacecraft. It is, however, important to have complete coverage such that a spatially small object or phenomena is not lost. Increasing overlap requires improved sensor performance over the nominal spatial resolution and increases data rates, and therefore, must be traded against attitude constraints. All three degrees of freedom influence coverage. Figures 1 and 2 illustrate these effects. It is desirable to have large limits on the amplitude as this results in fewer correction torques and less energy expelled. Also, during an attitude correction, imagery may be lost due to smear.



**Figure 1. Spacecraft Scan Coordinates**

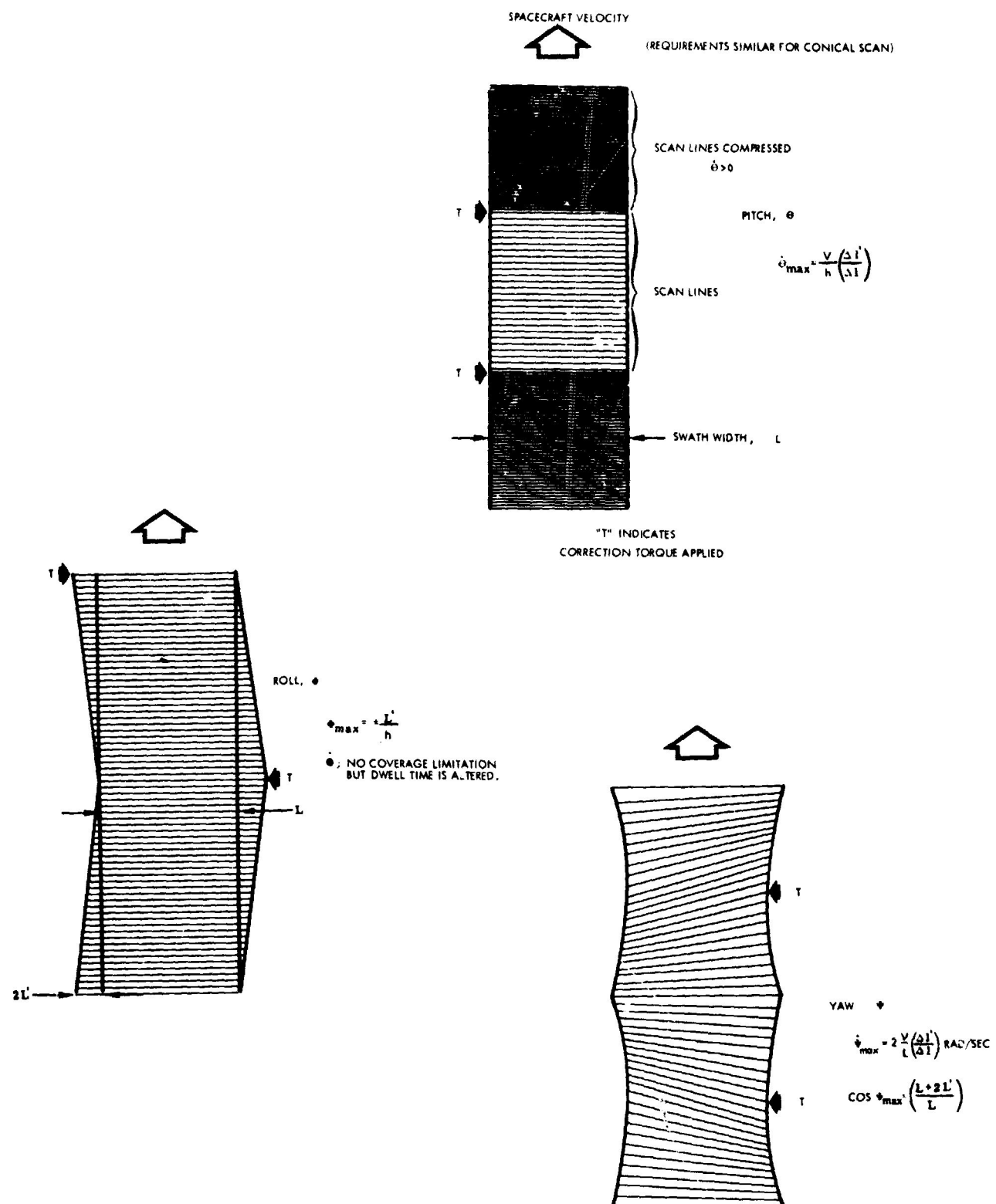


Figure 2. Predominant Scan Errors Introduced by Attitude Drift  
 (Figures exaggerated for clarity)

## APPENDIX E

### DISCUSSION OF SYSTEM ASPECTS OF PRECISION RANGING AND ALTIMETRY

#### Introduction and Summary

The requirements for precision ranging and altimetry which have been identified in this study pertaining to the three National priorities of Cartography, Hazards, and Fisheries require precision in the order of 10 cm to 25 cm. In performing precision ranging from orbital altitudes, one requirement becomes immediately apparent. Knowledge of the orbital ephemeris must be more accurate than the value specified for ranging accuracy.

#### The Ocean Surface Relative to a Geoid

If the ocean were in equilibrium, with no other forces acting on it than the earth's gravitational field, its surface would be a Geoid (an equipotential surface of the earth's field, allowing for the earth's rotation). Deviations of the surface from a geoid are due to a number of causes, such as:

- Tides
- Global circulation (ocean currents)
- Winds (air-sea interaction)
- Atmospheric pressure

In order to determine the deviation of the surface from a geoid, we need a sufficiently accurate measurement both of the geoid and of the height of the ocean surface. The determination of the geoid is discussed in the next paragraph. The height of the surface would be measured by a laser or radar altimeter. It will be necessary to determine the correction for wave height in order to measure the mean surface level.

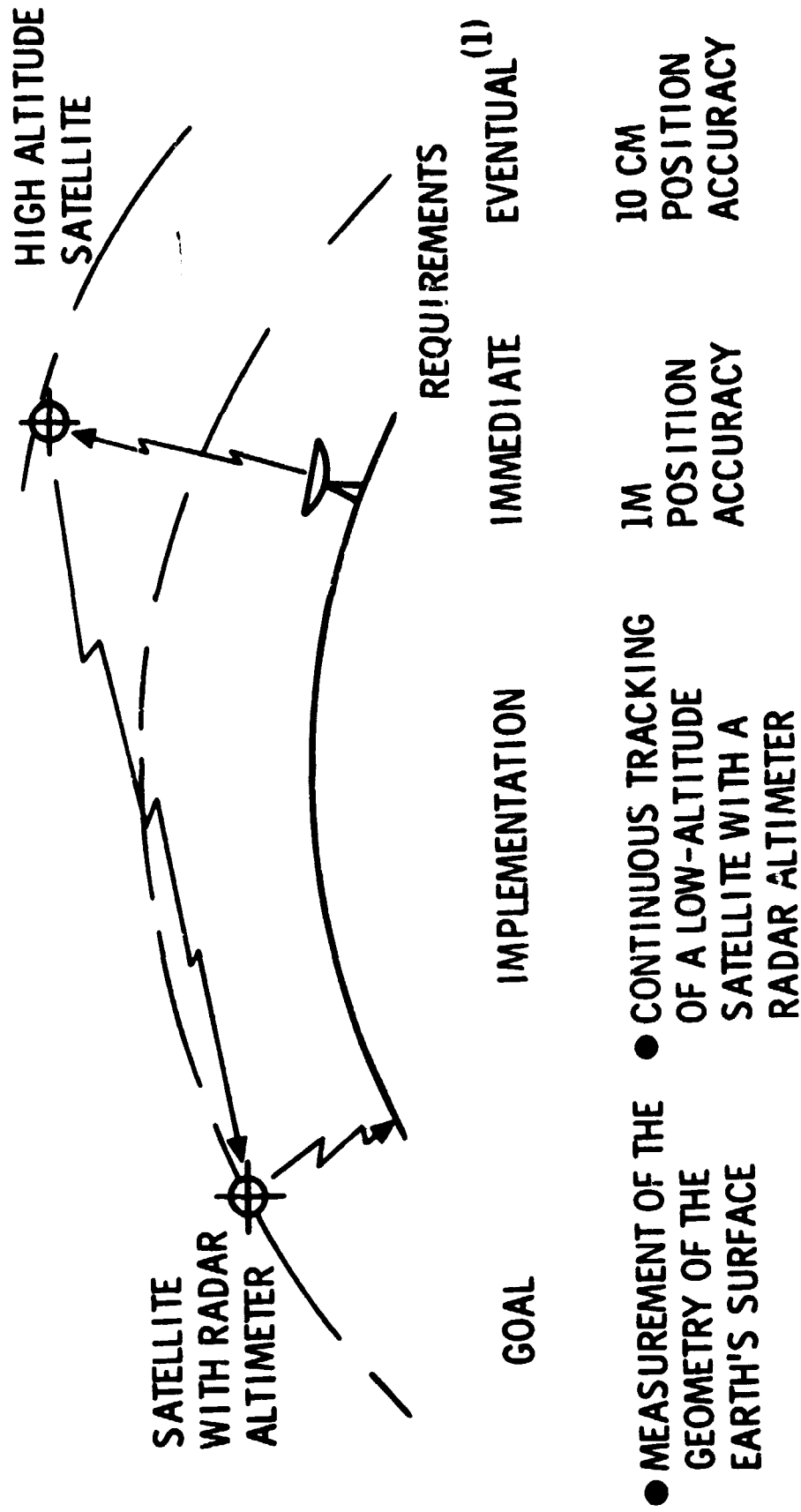
#### Orbital Considerations

The difficulty of accurately locating the altimeter in the satellite with respect to the geoid (mean sea level) surface is a major deterrent to

the use of satellite-borne radar or laser altimeters of 10 cm accuracy in the near future. It is feasible to determine the distance from the satellite to the smoothed ocean surface seen by the altimeter; however, the translation of this information into distance of the sea surface above (or below) the geoid surface. (This rather complicated problem requires solving for the geopotential both at sea level and at satellite level.) The data ultimately desired to 10 cm accuracy by oceanographers and solid earth geophysicists is this height of the ocean surface above the geoid.

To resolve this problem over the long range, it has been proposed in the NASA Williamstown Study<sup>(1)</sup> that high accuracy high-to-low satellite doppler tracking be employed. The equipotential surface at the geoid and the satellite's position relative to it would be determined from many continuous tracking passes over an ocean region of interest. High (probably synchronous) satellites would be used for tracking the low satellite carrying the altimeter. The high satellites could be accurately located relative to the geocenter by laser or radar trackers located on the continents (see Figure E-1). Then variations in the distance from the tracking satellite to the altimeter satellite could be resolved into components attributable to short-wavelength geopotential accelerations, long term drag effects, and the predictable variations due to the well known long-wavelength geopotential terms. The following section from Chapter 2 of the Williamstown Study<sup>(1)</sup> describes the accuracy which might be achieved in the next ten years from such a system.

In order to exploit the satellite altimeter measurements to the full, it is necessary to separate the effects of variations in gravity from the observed altitude. The only way this can be accomplished unambiguously is to determine the geoid independently. Because of the enormous number of coefficients needed to describe the geoid to this accuracy, possibly as many as  $10^4$ , it is not practical to calculate spherical harmonic coefficients through an analysis of orbital dynamics. The number of independent geodetic satellite orbits needed would be greater than 50, possibly in excess of 100. Furthermore, the amplitudes of the orbital perturbations associated with harmonics of degree greater than 50 are well below 0.1 mm and cannot easily be observed.



(1) REQUIRES FURTHER DEVELOPMENT OF INSTRUMENTATION AND TECHNIQUES

Figure 1. System Implementation to Measure the Height of the Ocean Surface

The method used successfully by Muller and Sjogren<sup>(2)</sup> to obtain the gravitational field of the front face of the moon should be applicable to this problem. The method is to deduce the acceleration of a satellite from doppler measurements, which provides a direct measure of the component of force acting on the satellite parallel to the propagation path. By observation of the doppler shift over a sufficient number of orbits, it is possible to obtain a very detailed gravimetric map through direct observation.

Assuming that variations in kinetic energy can be translated into variations in potential energy, doppler measurements with an accuracy of 0.1 mm/sec between a stationary satellite and a satellite in a low orbit will be adequate to map variations in the equipotential at satellite altitude to 10 cm. The accuracy with which this can be translated into geoidal variations depends on satellite altitude, the analytical techniques available, and how long an averaging time is acceptable. We estimate that a doppler measuring accuracy of 0.03 to 0.05 mm/sec for averaging times of 10 sec will be needed to determine the geoid to an accuracy of 10 cm.

The data used by Muller and Sjogren were obtained with a two-way doppler system using earth-based transmitters and receivers and a transponder in the Lunar Orbiter. The uplink frequency of 2115 MHz was controlled by a rubidium frequency standard. The transponder multiplied this frequency by 240/221, resulting in a downlink frequency of 2300 MHz. The doppler shift was then obtained by beating the received downlink signal with the rubidium standard. The accuracy of the doppler measurements was in the neighborhood of 2 mm/sec.<sup>(3)</sup>

Using an identical system for the synchronous-to-low-altitude satellite measurement should result in doppler-shift accuracies of at least 0.3 mm/sec. The improvement results from three factors: elimination of tropospheric propagation effects, reduction by a factor of about 2 in the ionospheric effects, and reduction of the total propagation time by a factor of 10, improving the "coherence" of the signal that has made the round trip with the signal it is compared with in the receiver.

Further improvement can be obtained by use of either a two-frequency pair at or above 1000 and 2000 MHz or a single frequency above 20 GHz<sup>\*</sup> to eliminate ionospheric errors. If the doppler shift were integrated over 10-sec intervals and the number of cycles were measured to a precision of 5 nsec, which is quite reasonable, the counting error would be equivalent to 0.015 mm/sec. (Errors such as this can be further reduced by taking account of their well-defined statistical properties.) We estimate such a system should produce a range-rate accuracy of 0.1 mm/sec. We believe it is possible within the time scale of the Earth Physics Program to achieve accuracies at a level of 0.03 mm/sec.

#### System Aspects

In order for the ERTS E/F satellite to meet the requirements of the three National priorities for precision ranging and altimetry, a special condition would have to be met. Continuous precision tracking of ERTS E/F from one or more high altitude (i. e., synchronous orbit) satellites would be required in order to obtain a precise measurement of the ERTS E/F ephemeris. Tracking from ground stations is not adequate due to lack of continuous coverage.

#### Conclusion

It is unlikely that this special set of conditions will be compatible with the ERTS E/F mission. It is therefore recommended that the function of precision ranging and altimetry be not considered for the ERTS E/F mission.

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\*It is of interest to note that selecting a frequency above 20 GHz, which is absorbed in the troposphere, could solve a frequency-allocation problem, since these signals would not be detected on the ground.

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## APPENDIX F

### NOISE CONSIDERATIONS IN SILICON DETECTOR ARRAYS

Four multispectral imaging sensors have been proposed for use in obtaining observations for the four national priorities of Geography/Hydrography/Cartography, Hazards, Pollution, and Fisheries. Each of these utilizes high-density arrays of silicon detectors. A discussion of the noise characteristics of these arrays follows.

The ultimate sensitivity of a photoconductor in terms of the minimum radiation signal which can be detected is given by the ratio of signal to noise in the photoconductor.<sup>(1)</sup> A general survey of noise processes in photoconductors as a function of frequency is given in Figure F-1, according to Rose.<sup>(2)</sup> There are a number of different sources for noise in a photoconductor: (1) Johnson or Nyquist noise — the fundamental noise present in any resistance in thermal equilibrium with its surroundings — important only for high frequencies; (2) generation-recombination noise — due to fluctuations in the density of free carriers because of fluctuations in the absorption of photons, in the absorption and emission of background radiation, and in the absorption and emission of phonons — important mainly for intermediate frequencies; and (3)  $1/f$  noise prominent at low frequencies — probably associated with surfaces, barriers, and poor contacts. In Figure F-1, the frequencies  $f_1$ ,  $f_2$  and  $f_3$  represent the reciprocal lifetimes of trapped charges near a barrier contact;  $f_4$  is the reciprocal lifetime of photo-excited carriers;  $f_5$  is the reciprocal lifetime of thermally excited carriers; and  $f_6$  is the reciprocal relaxation time (RC product) of the photoconductor.

Noise currents are random and are added as the square of each noise generator considered separately. Low frequency noise,  $1/f$ , has no quantitative theory but is believed to originate detector surface, contacts and configuration boundaries. Since low frequency noise decreases with increasing frequency, the noise for silicon detectors measured usually disappears beyond 250 cycles per second. Depending on the conditions of background radiation, the detector is usually  $1/f$  noise limited below 200 cycles per second.<sup>(3)</sup>

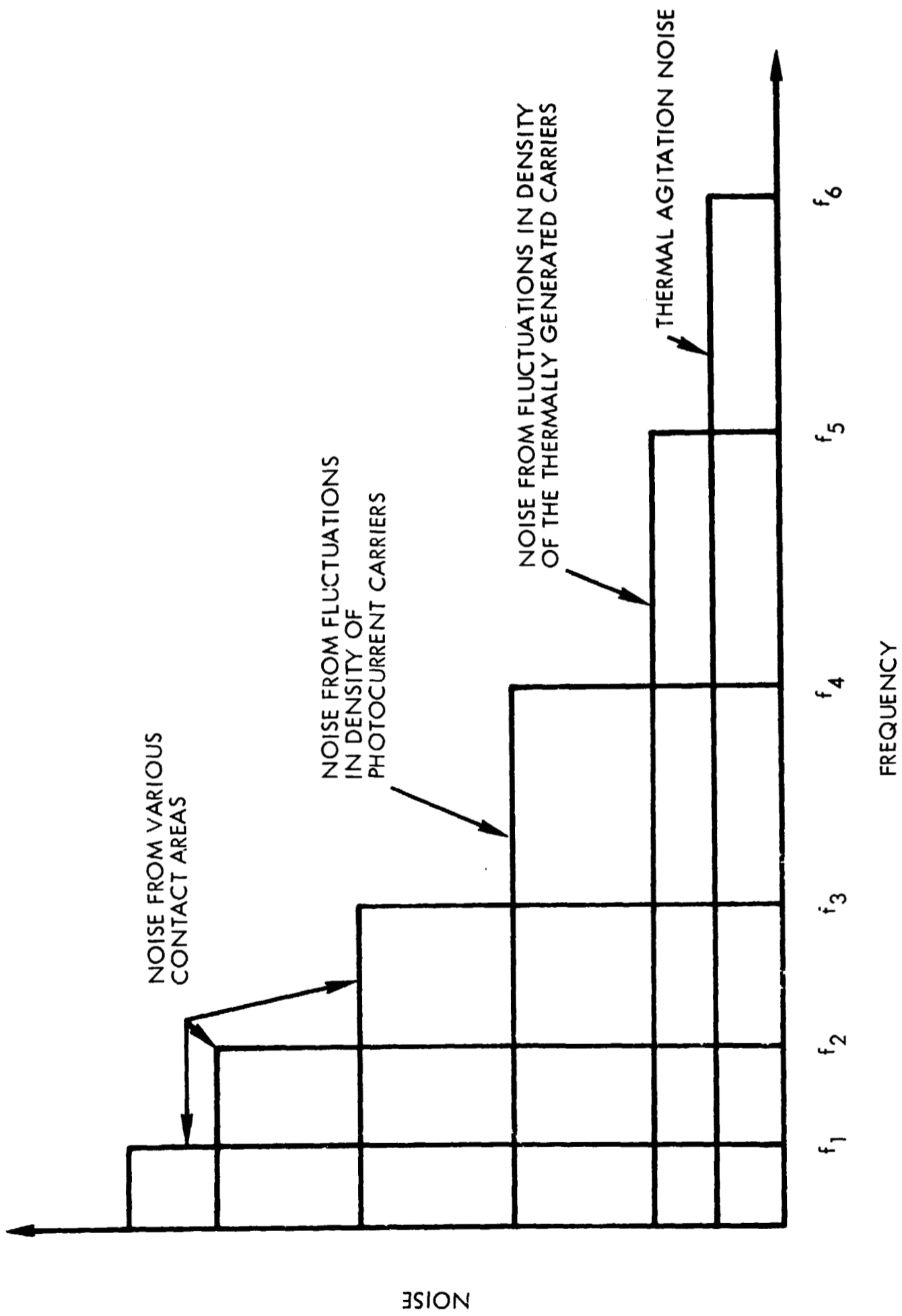


Figure F-1. Sources of Noise in Photoconductors

The following equation can be used to define the several noise components. (4)

$$i_n^2 = \left[ \frac{k_1 I_1^2}{f} + \frac{k_2 I_2^2}{1+(f/f_1)^2} + \frac{k_3 I_3^2}{1+(f/f_2)^2} + \frac{4KT}{R} \right] \Delta f \quad (F-1)$$

where

$i_n$  = total noise current, in amperes rms

$k_1, k_2, k_3$  = empirical constants

$f$  = bandwidth, Hz

$f_1$  = cutoff frequency of generation-recombination noise, determined by free carrier lifetime, Hz

$f_2$  = cutoff frequency of thermally generated carriers, determined by carrier lifetime, Hz

$I_1$  = bias or excitation current, in amperes rms

$I_2$  = photocurrent, amperes rms

$I_3$  = thermally generated current, amperes rms

$K$  = Boltzmann's constant

$T$  = temperature, in degrees Kelvin

$R$  = photoconductor resistance, ohms

In the multispectral sensors configured for use in oceanographic applications in this study, optics of low f-number have been used in order to obtain a high level of cell irradiance in order to obtain near-photon noise limited operation of the detector arrays.

For an array having a ground resolution of 100 ft. from an orbital altitude of 300 nmi, the dwell time per element will be 2.2 msec, and each element of the array will have an electronic bandwidth of  $1/2t = 227$  Hz. Thus some contribution to the total noise current by  $1/f$  noise may be anticipated. In addition, some amount of noise due to electronic switching will be present.

The specific figures for multi-element arrays using electronic interrogation are highly dependent upon the specific type of array which is selected — the values being different for photodiode and phototransistor arrays, for the photovoltaic or photoconductive mode of operation, and also depending upon the nature of the switching electronics.

In the multispectral sensor configurations which have been presented, performance is specified based upon photon-noise limited operation of the arrays. The performance figures will be degraded to some extent by the additional noise effects defined above. The exact amount of degradation will be dependent upon a detailed design study using noise figures for the specific type of array selected. Data of this type is at the present time in the classified domain.

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